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High Speed Research System Study Advanced Flight Deck Configuration Effects

Jay R. Swink
Richard T. Goins

DOUGLAS AIRCRAFT COMPANY
Long Beach, California

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CONTRACT NAS1-19345
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FOREWORD

The Advanced Flight Deck Configuration Effects (Task Assignment 12) was added to NASA's 1991 High-Speed Research Program system study contract with Douglas Aircraft Company (DAC) by a task order dated 1 July 1991. The work was directed by NASA Langley Research Center (LaRC), whose technical task monitor was Jack Hatfield, and was funded under Contract NAS1-19345 covering the period of performance through March 1992.

The principal investigator was Jay R. Swink, ably assisted by Richard T. Goins and the technical staff of the Advanced Commercial Programs - HSCF team, particularly H. Robert Welge, program technical management; Alan K. Mortlock, environmental assessment; Munir Metwally, economic assessment; Brian Lindley, configuration; Ray Dahl, weights; and John Morgenstern, Roland Schmid, aerodynamics.

The support and coordination of Sam Morello, FltMD, NASA LaRC is specifically acknowledged.

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ACRONYMS AND ABBREVIATIONS

AAS	Advanced Automation System
ADS	Automatic Dependent Surveillance
AERA	Automated En Route ATC
AFS	Automatic Flight System
AGL	Above Ground Level
AMASS	Airport Movement Area Safety System
ASTA	Airport Surface Traffic Automation
ATC	Air Traffic Control
ATLS	Automatic Terminal Information Service
ATM	Air Traffic Management
ATN	Aeronautical Telecommunication Network
AWOS	Automated Weather Observing Station
CG	Center-of-Gravity
C/N/S	Communication/Navigation/Surveillance
CO	Carbon Monoxide
DEP	Design Eye Point
DOC	Direct Operating Costs
EATP	Engineering Authority to Proceed
ELS	Electronic Library System
FMS	Flight Management System
FOD	Foreign Object Damage
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPWS	Ground Proximity Warning System
HC	Hydrocarbon
HSCT	High-Speed Civil Transport
HRSP	High-Speed Research Program
IWVS	Integrated Wake Vortex System
LLWAS	Low Level Windshear Alert System
MLS	Microwave Landing System
NAS	National Airspace System

ACRONYMS AND ABBREVIATIONS

NASA	National Aeronautics and Space Administration
NO _x	Nitrogen Oxide
PF/PNF	Pilot Flying/Pilot Not Flying
SL	Sea Level
SVS	Synthetic Vision System
TATCA	Terminal ATC Automation
TCAS	Traffic Alert and Collision Avoidance System
TDWR	Terminal Doppler Weather Radar
TOGW	Takeoff Gross Weight

High Speed Research System Study Advanced Flight Deck Configuration Effects

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SUMMARY

The high-speed civil transport (HSCT) proposed for the early-2000s has unique characteristics and special flight deck design challenges which are a result of differences in speed, altitude, range, operational aspects, and physical-design characteristics from those of subsonic transports. As a result of several meetings and workshops between NASA, Boeing, Douglas, and Honeywell, many of the technical challenges associated with the development of a safe, efficient flight deck, and the associated systems, for a future Mach 2.4 HSCT have been identified. Successfully meeting these challenges with new flight deck concepts, systems designs, and appropriate technologies may have high payoff in terms of benefits for *airframers*; additional sales and profits, *airlines*; cost-of-ownership, efficiency of operation, and expanded markets, *passengers*; safety and schedule reliability, the *Air Traffic Management System (ATM)*; enhanced efficiency and capacity, and the *Nation*; improved business environment and balance of trade.*

In mid-1991 NASA contracted with industry to study these flight deck challenges and assess the benefits, prior to initiating their High Speed Research Program (HSRP) Phase II efforts, then scheduled for FY93. The following presents the results of this nine-month effort and highlights a number of the most significant findings and recommendations for three (3) specified advanced concepts, a) a no nose-droop configuration, b) a far forward cockpit location, and c) advanced technology crew monitoring and control of complex systems.

In summary, the results indicate that the no nose-droop configuration is critically dependent upon the design and development of a safe, reliable, and certifiable Synthetic Vision System. A droop-nose configuration would cause significant weight, performance, cost penalties. A far forward cockpit location with conventional side-by-side seating provides little economic advantage, however, a configuration with a tandem seating arrangement provides a substantial increase in either additional payload (i.e., passengers) or potential for downsizing the vehicle with resulting increases in efficiencies and reductions in emissions. Without a droop nose, external visibility is eliminated and takeoff/landing guidance and control must rely on synthetic vision. The technologies enabling such capabilities, which de facto provides for Category III all-weather operations on every flight, independent of the weather, represents a dramatic benefits multiplier in a 2005 global ATM network; both in terms of enhanced economic viability and environmental acceptability.

* from Background section of proposed statement of work for Flight Deck Systems Studies Task, NASA, May, 1991.

INTRODUCTION

Shortly after the turn of the century the next generation High-Speed Civil Transport (HSCT) will be introduced into commercial operations, replacing the current supersonic transport; the Concorde. This vehicle will not only represent a whole new generation of airframe and propulsion technologies, but a totally new operational environment consisting of increased environmental restrictions within a highly automated global air traffic system. This situation presents a number of interesting challenges, none of which are greater than those confronting the flight deck designer.

In response to these challenges, NASA initiated a number of system study efforts in the late 1980's as part of their High Speed Research Program (HSRP). These studies were designed to investigate the commercial viability of the proposed technology solutions as well as determine the impact of environmental issues on the aircraft. In 1991 the flight deck was included as a key system and tasking called for the evaluation of economic benefits and environmental enhancements of advanced flight deck concepts.

The flight deck system study was based on a set of conceptual configurations including: a) no droop-nose; b) a far forward cockpit location; and c) the flight crew monitoring/control of complex systems and advanced technologies, enabling a two-place crew to safely and efficiently operate the HSCT. These configuration options supported an operational concept of a Mach 2.4 aircraft with a 5,500 mile range and having a payload of 300 passengers designed to operate globally in a 2005 Air Traffic Management system which provides flow control and all-weather takeoff and landing capabilities.

The most demanding challenge for the flight deck designers was lack of a droop nose which meant that the HSCT would not have sufficient forward external visibility to permit conventional takeoffs and landings. Instead, it would have to rely on a synthetic vision system to provide the pilots with precision guidance and control cueing. A secondary challenge was to provide conceptual crew station designs which would accommodate a far forward location, necessitated by the extremely pointed nose of the supersonic airframe planform, without compromising revenue generation capability. Finally, a set of options were examined for the advanced crew systems and technologies needed to support a far forward cockpit with no forward external visibility, and an operational concept which was Category III all-weather throughout and entailed extensive automation, both on the ground and in the air, for enhanced performance efficiency and safety as well as environmental acceptability.

This report summarizes the results of the Flight Deck Configuration Effects (Task 12) for the HSR system studies contract for the period from July 1991 through March 1992. The Technical Approach presents the Statement of Work conducted in two segments; a requirements analysis; the conceptual approaches and related configuration definition; and the methodology utilized for the performance and economic assessments. Next is presented the study findings, both in terms of economic benefits and environmental enhancements associated with the advanced flight deck concepts, as well as a series of recommendations for follow-on activities and the criticality of maintaining a continuation of flight deck studies prior to the Phase II HSR effort. It also includes a definition of a formal, systematic design and development approach for advanced flight decks, be they subsonic or supersonic, to capture the synergy of common technology innovations within a changing global operational environment.

TECHNICAL APPROACH

OVERVIEW

The technical approach for the Advanced Flight Deck Configuration Effects (Task Assignment No. 12), as part of the High Speed Research (HSR) system studies contract, was based on the following Statement of Work (SOW):

TASK ASSIGNMENT NO. 12 - ADVANCED FLIGHT DECK CONFIGURATION EFFECTS

12.0 The objectives of this task are to evaluate the environmental benefits and economics enhancements of advanced flight deck concepts appropriate for HSCAT aircraft designed for an entry-into-service date of 2005. Specifically, this task will provide analyses of flight deck concepts and systems which permit safe and efficient HSCAT operation using a two-person flight deck crew under the following conditions:

- (1) No nose-droop configuration (Concept A)
- (2) Far forward cockpit location (Concept B)
- (3) Advanced technology crew monitoring and control of complex systems to reduce fuel reserves (Concept C)

12.1 The Contractor shall identify the flight deck system operational requirements, conceptual approaches, and technologies required to meet the conditions above.

12.2 The Contractor shall conduct configuration layouts and assess the design and development approach required to accommodate the advanced concepts.

12.3 The Contractor shall define the empty weight impact of the three advanced concepts.

12.4 The Contractor shall conduct separate sizing studies for concepts (A), (B), and (C) and a fourth sizing study for a combination of all three concepts. The Contractor shall determine the differences in mission performance using the advanced concepts relative to conventional configurations.

12.5 For concept (C), the Contractor shall conduct mission performance studies to assess the reductions attainable in reserve fuel and the economic benefits of improved all-weather take-off and landing capability.

12.6 The Contractor shall evaluate the benefits in overall operating economics and any improvement in environmental acceptability (i.e., community noise, atmospheric emissions impact, and sonic boom) for all three concepts.

12.7 The Contractor shall commence Tasks 12.1 and 12.2 and deliver an oral status report at the end of Fiscal Year 1991. The overall task shall be completed and a written report provided by the end of the 2nd quarter of Fiscal Year 1992.

As indicated in the Statement of Work, the task was performed in two (2) major segments. The first segment in FY91 covered; 1) identification of the operational requirements, 2) the conceptual approaches, and 3) the technologies required to satisfy those requirements, as well as, conducting preliminary configuration layouts and assessing the design and development approach that will address the advanced concepts. The second segment, covering the FY92 efforts, was to 1) define weight impacts, 2) conduct sizing studies, and 3) conduct mission performance studies and assess economic benefits and 4) evaluate overall benefits in operating economics and improved environmental acceptability.

The first segment was performed from 1 July through 27 September, 1991 and the status was briefed at NASA's Langley Research Center (LaRC) on 30 September. The briefing addressed the definition of HSCCT operational requirements in the year 2005, an assessment of the technology needed to meet those requirements, particularly in the area of the no nose-droop (Concept A) enabling technology of synthetic vision; an examination of far forward cockpit locations (Concept B); and the investigation of the advanced technologies and complex systems (Concept C) the two-place crew must monitor and control to achieve safe and efficient all-weather (Category III) capabilities. This segment also examined preliminary configuration layouts for both a side-by-side crew station and a tandem seating arrangement. Additionally, a formal, systematic flight deck design and development process was defined which would accommodate development of advanced concepts for a HSCCT flight deck during Phase II of the HSR effort.

The second segment was conducted from 1 October 1991 through 31 March 1992. An interim briefing was presented on 21 January 1992 at NASA LaRC. That briefing covered refinements and trade-offs in preliminary configuration layouts; perspective drawings of the side-by-side and tandem seating arrangements; and an outline of weight, sizing, and performance assessments to be submitted to economic analysis and evaluation of environmental impacts. A final briefing was presented on 7 April 1992 at LaRC which covered the performance, economic, and environmental analyses and assessments conducted through the end of the second quarter of FY92. Results of these efforts are presented in the Findings and Recommendations.

SEGMENT ONE (FY91)

Segment One covered the period from 1 July through 30 September 1991 and included task 12.0 through 12.2 of the Statement of Work. The basic tasking in this segment called for the performance of Task 12.1 consisting of three (3) contractor efforts for the identification of:

- flight deck operational requirements
- flight deck conceptual approaches
- flight deck technologies required

IDENTIFICATION OF OPERATIONAL REQUIREMENTS

The identification of the HSCCT flight deck operational requirements was derived from the baseline configuration used in the 1990 system studies¹ and an identification of the functional/system requirements for future transport aircraft² which examined the operational environment (e.g., National Airspace System[NAS])for the 2005 era. The list of operational requirements in Table I summarize the results of this initial task. Additionally, a series of point papers were developed to narratively summarize these changing operational conditions and are presented in the Appendices under the titles "*The NAS and the HSCCT*" (Appendix A) and "*The Role of ASTA in Support of HSCCT*" (Appendix B).

SPEED - Mach 2.4 - 75% supersonic/25% subsonic (M.95)

ALTITUDE - 68,000 feet cruise altitude

RANGE - 5,500 NM

CREW - Two (2) person crew; Captain & First Officer

OPERATIONAL CRITERIA :

- ~ 800 Klbs TOGW from 11,000' field length, Standard Day @ SL (35' obstacle)
 - Constant climb speed $V_2 + 10$, 4' climb gradient
 - All weather, All site operations & minimum special Air Traffic Management (ATM) handling
 - Category III Landing capability
- Compatible with circa 2005 Air Traffic Management (ATM) system:
 - Advanced Automation System (AAS) ATC (Air Traffic Control)
 - AERA (Automated EnRoute ATC) II/III and terminal flow management
 - Advanced communications/navigation/surveillance (C/N/S) systems
 - Mode S and satellite digital data link communications
 - Global Positioning System (GPS) and Microwave Landing System (MLS)
 - Automatic Dependent Surveillance (ADS) via satellite
 - Airport Surface Traffic Automation (ASTA)
 - Airport Movement Area Safety System (AMASS) for runway incursion alerting
 - Mode S multilateration system for surface traffic management
 - Two-way Data Link for active taxi-route guidance and conformance monitoring integrated with other ATM system automation

HSCCT - TABLE 1

Table I. Summary of Operational Requirements

CONCEPTUAL APPROACHES

The identification of the flight deck conceptual approaches associated with the advanced concepts given in Task 12.0 of the Statement of Work (i.e., Concept A - no nose-droop, Concept B - far forward cockpit, Concept C - advanced crew technology/systems monitoring) were combined with the identification of the technologies required to meet these conditions.

In the case of Concept A, this consisted of identifying the technologies needed to design and develop a safe, reliable, and certifiable Synthetic Vision System (SVS) which would enable a HSCT to operate without adequate forward external visibility if no droop-nose was provided. These results are presented in Table II. (Additionally, for comparison purposes, a droop-nose configuration was developed and sized in Segment Two to further quantify the weight/performance penalties associated with such a vehicle).

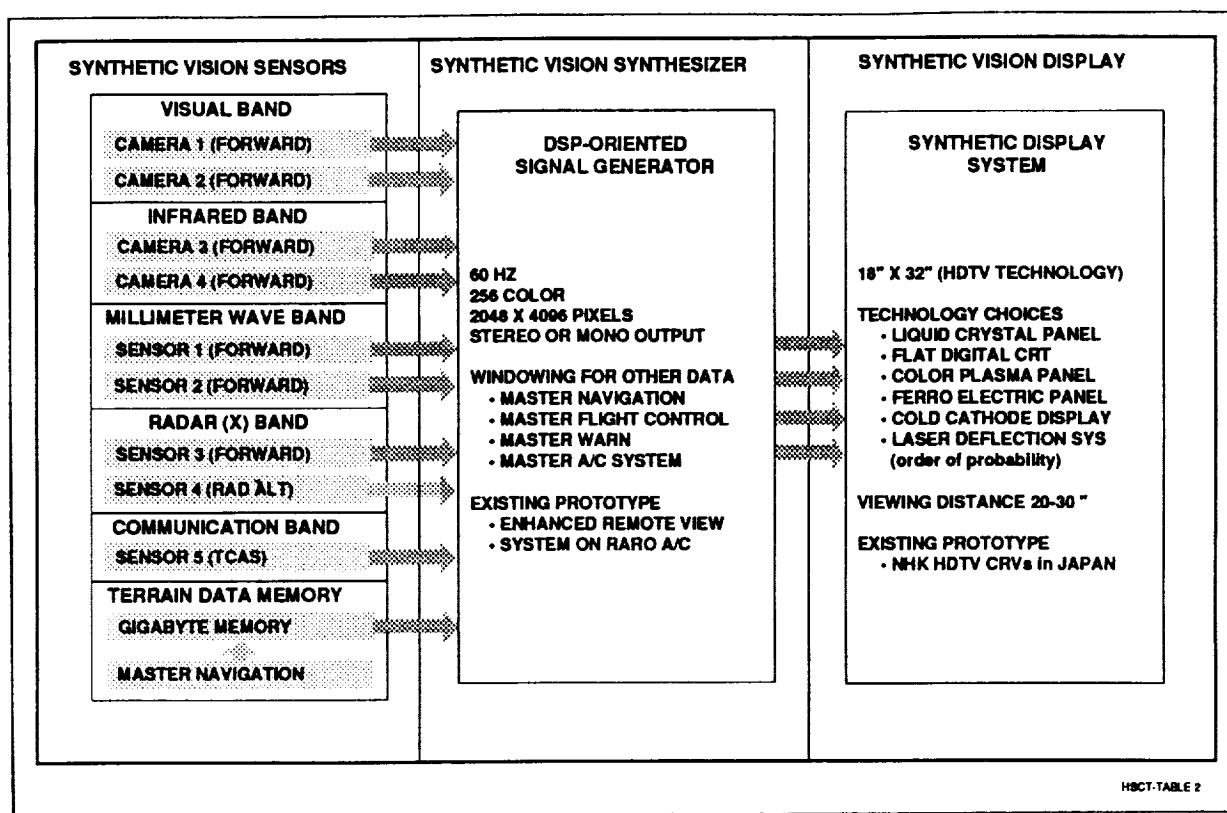


Table II. Synthetic Vision Technologies

Concept B (far forward cockpit) consisted primarily of two options: 1) conventional side-by-side seating arrangement and 2) a non-conventional tandem arrangement. The side-by-side option provides for nominal "mirror image" layouts of controls and displays, traditional crew coordination cross-referencing between crew positions, and enables derivative transport cockpit configurations to be utilized. However, because of space constraints associated with the extremely long, tapered nose of the baseline HSCT planforms, the side-by-side arrangement is severely limited in the amount of forward movement of the cockpit. These limitations consist of restrictions in both lateral and vertical crew clearances due to the conical shape of

the forward fuselage. On the other hand, a tandem seating arrangement allows the crew to be aligned fore and aft, without affecting separation clearances. This configuration also allows for differential seating heights. The tandem seating arrangement is used successfully in many military air vehicles without compromising crew coordination. It also provides an opportunity to layout identical control and display configurations in both crew stations and, because external visibility is not a consideration, the design eye point (DEP) for shared vision/reach accommodation is eliminated from differential pilot flying/not flying (PF/PNF) locations and/or distinctions. Additionally, this tandem crew seating (actually an offset/differential height, over-the-shoulder arrangement) allows the crew stations to be moved forward 66 inches from the original position. (Later analyses in Segment Two indicated that a forward movement of 96 inches was possible). These two options are summarized in Figure 1 and a description of the approach used to examine these options are discussed in *"HSCT Configuration Layouts"* (Appendix C). A later refinement in the methodology is available in Appendix D, *"HSCT Crew Station Configuration Studies"*.

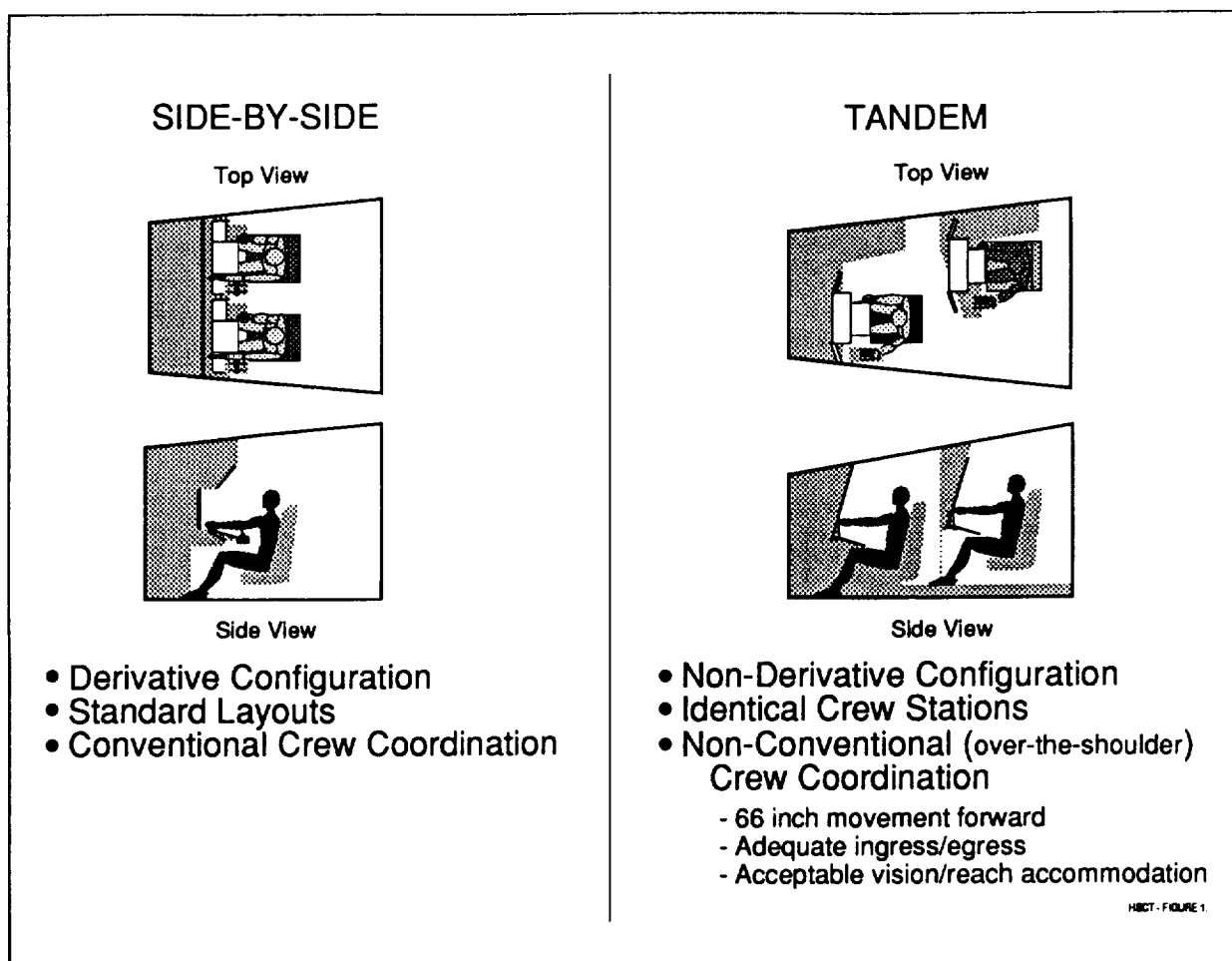


Figure 1. Concept B - Far Forward Cockpit Location

TECHNOLOGY REQUIREMENTS

In terms of the technologies supporting Concept B, the major focus was on the cockpit displays for synthetic vision. As indicated in Table 2 the primary display was postulated to be a 18" X 32" High-Definition Television (HDTV). Because of the far forward location which imposed horizontal (width) constraints within the cockpit area, the HDTV, large screen display was oriented with the long axis (i.e., 32") in a vertical plane as shown in Figure 2. The issues of image quality (e.g., resolution, magnification), field-of-view (FOV), and pictorial display format/symbology were not addressed in detail.

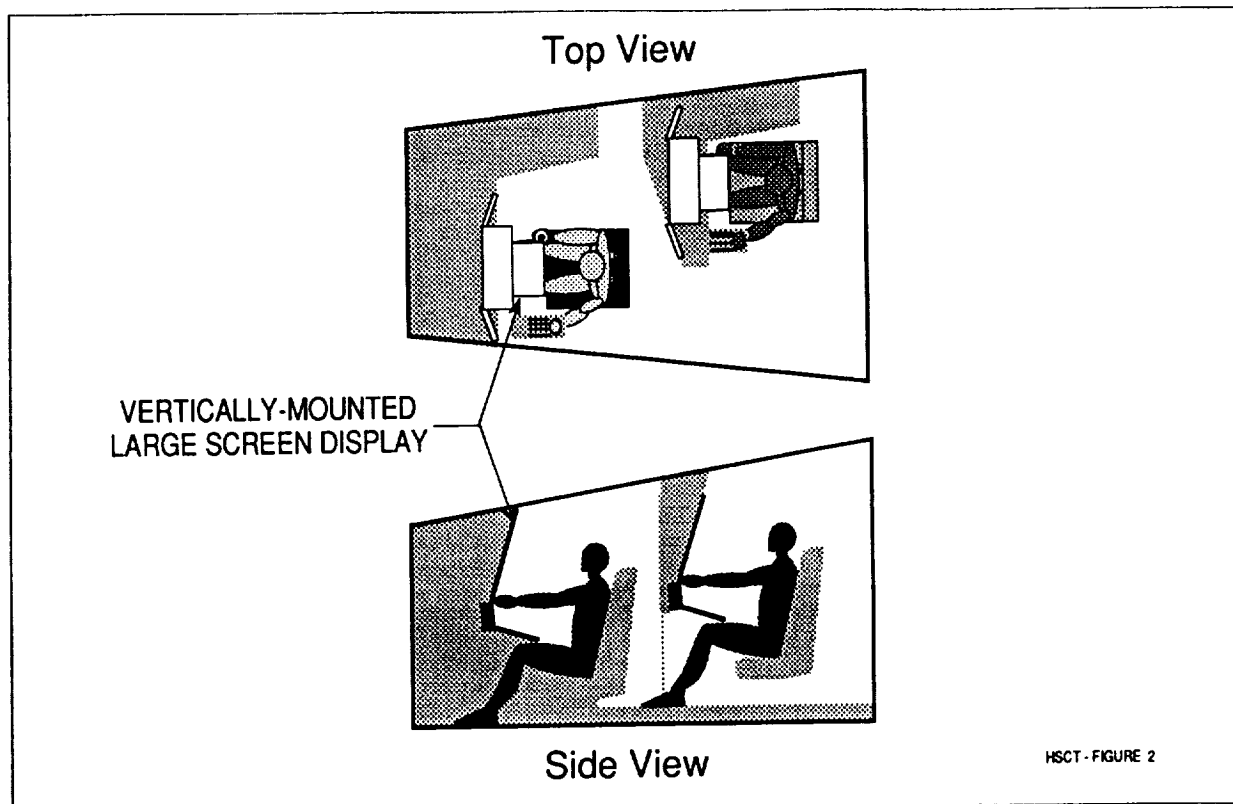


Figure 2. Large Screen VSD - Tandem Arrangement

A narrative description of the other cockpit displays can be found in Appendix E entitled *"HSCT Cockpit Displays"* as well as sample display formats for various mission segments (e.g., ground roll, rotation, climbout, approach/landing). Also as part of this technology assessment, a set of design guidelines for electronic control/display systems were developed for the HSCT (Appendix F).

The Concept C (advanced technology/system crew monitoring) efforts analyzed mission profiles particularly in two critical mission segments: 1) takeoff/departure, and 2) approach/landing. The analysis of each is shown graphically in Appendices G and H, respectively. These profiles, along with a narrative scenario entitled *"Fasten Your Seat Belts"*, (Appendix I) and *"Prepare for Landing"* (Appendix J) provides a basis for examining crew activities, time-lines, and postulating various system automation requirements. The latter was also supported by a point paper entitled *"The Path to the Future"* (Appendix K).

Based on these operational scenarios, mission profiles, technology projections, and the baseline configuration documents for HSCCT, a list of proposed advanced technologies to enhance performance efficiency, requiring crew system monitoring and control, was developed (Table III); along with a set of alternative system automation concepts and procedures that might be considered (Table IV).

<ul style="list-style-type: none"> • Integrated Flight/Propulsion Control System <ul style="list-style-type: none"> - Flight path control - Thrust management • Aerodynamic Reconfiguration Monitoring <ul style="list-style-type: none"> - Laminar flow control - High lift devices • High-Speed Parameter Management <ul style="list-style-type: none"> - Noise contour and abatement profiles - Sonic boom minimization - Atmospheric emissions - High altitude skin temperature/solar radiation • Unique Operational Environment <ul style="list-style-type: none"> - Integrated Communications/Navigation/Surveillance (C/N/S) - Data Link, GPS/MLS/, ADS - Integrated Air Traffic Management (ATM) - Automated flow control

HSCCT-TABLE 3

Table III. Concept C - Advanced Technology Systems Monitoring

<ul style="list-style-type: none"> • Takeoff <ul style="list-style-type: none"> - Augmented takeoff power (Afterburner) - Automatic rotation $\leq 13^\circ$ • Climb-out <ul style="list-style-type: none"> - Continuous power reduction - 24° - 28° climb angle - Power cutback to 4% gradient - Flap retraction schedule (leading and trailing edge) • High-Speed Trim <ul style="list-style-type: none"> - CG/Fuel management - Nozzle thrust vectoring - Front flap manipulation • Approach <ul style="list-style-type: none"> - High approach speed (> 165 kts) - Higher Glide Slope ($\geq 4-5^\circ$) - Decelerating Approach Speeds <ul style="list-style-type: none"> 200' \Rightarrow 145 kts 1000' \Rightarrow 200' AGL

HSCCT-TABLE 4

Table IV. Alternative System Automation Concepts

Additionally, a concept referred to as "operational towing" was examined as an alternative to imposing a series of unique ground operating requirements upon a synthetic vision system. The need to safely taxi and navigate to and from the gate to runway with no external vision could be handled by towing the HSCT; assisted by the ASTA capabilities being developed for use in the latter part of this decade. Table V summarizes the advantages of such an approach which includes both enhanced economic and environmental effects.

OPERATIONAL TOWING VS AUTONOMOUS TAXIING	
Concept Utilized in Europe for Environmental Reasons	
<ul style="list-style-type: none"> • Towbar-less tractor, interchangeable among aircraft types <ul style="list-style-type: none"> - Higher towing speeds with tug (18/20 mph) - One man operation and less brake/tire wear - Considerable fuel savings (≈ 18%) - Reduced risk of engine (FOD) damage - Saving of engine running time - Reduced environmental impact (noise and emissions) - Enhanced accuracy/safety of operations • Compatible with Airport Surface Traffic Automation (ASTA) <ul style="list-style-type: none"> - Expanded visual guidance - Enhanced surveillance/conformance monitoring - Electronic surface map display (tower/cockpit) - Two-way data link communications 	HSCT TABLE V

Table V. Alternative Ground Operations

Generally, the totality of this information provides a qualitative impression that the HSCT and its unique supersonic requirements, and associated technologies, would challenge a two-person crew, both in the terms of workload under normal visual conditions to say nothing of the additional burden of continuous Category III operations.

The latter (viz. continuous Category III), however, may not represent the major impediment to safe and effective operations, as previously assumed, and discussed in a point paper entitled *"To See or Not To See"* (Appendix L). The technology certainly exists, through systems automation; appropriate crew interfacing; and integration with a new global air traffic management system; to operate under Category III all-weather conditions continuously. User acceptance, however, may be a different matter!

Configuration Layouts -

The first part of Task 12.2, calling for configuration layouts, was adequately covered under the Concept B efforts, except for a customer requested modification to reexamine the side-by-side configuration utilizing a horizontal display width of 30" versus the previous 40" width. (This revision to the side-by-side configuration was conducted during Segment Two and its impact of forward movement is covered in Appendix M.)

Design/Development Approach -

The final effort in Segment One, as called for in Task 12.2, was to assess the design and development approach for flight decks which would accommodate these advanced concepts (e.g., no nose-droop, far forward cockpit, and advanced technology/system crew monitoring and control). What was proposed is the "totally integrated systems approach" outlined in Figure 3.

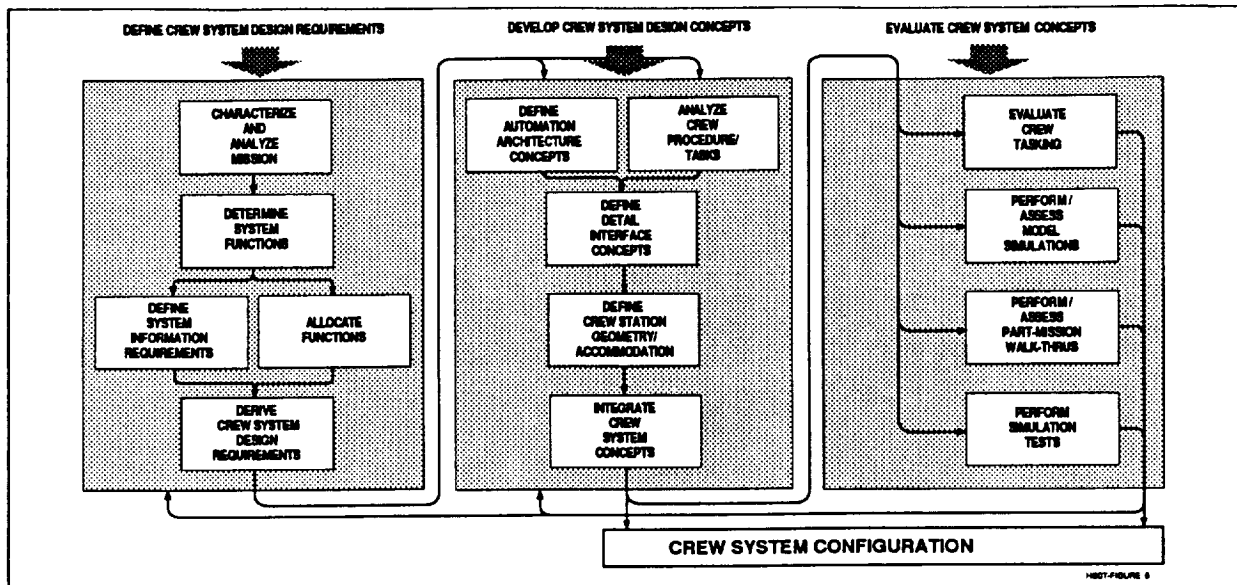


Figure 3. Totally Integrated Systems Approach

A summary of the Segment One preliminary conclusions, as briefed to NASA LaRC's technical monitors and HSR system study personnel, on 30 September, 1991, is presented in Figure 4.

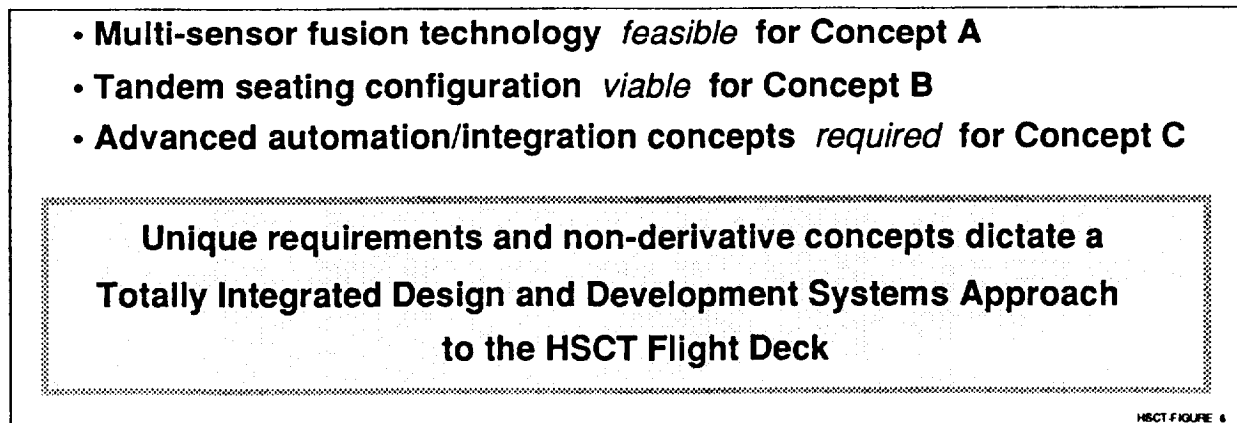


Figure 4. Preliminary Conclusions

SEGMENT TWO (FY92)

Segment Two was conducted from 1 October 1991 through 31 March 1992. The activities covered the Statement of Work Tasks 12.3 - 12.6 technical efforts, plus an oral and written report in accordance with Task 12.7.

The initial tasking for this segment (12.3 and 12.4) was to:

- define the empty weight impact
- conduct separate sizing studies
- [for advanced concepts (A,B, and C) and combinations], and
- determine mission performance differences relative to conventional configurations

WEIGHT AND SIZING STUDIES (Tasks 12.3 and 12.4)

The first task was to develop a droop-nose configuration, size it, and weigh it for comparison against the no nose-droop baseline. The second task was to compare the weight and sizing for both a side-by-side and a tandem far forward cockpit location configurations (see perspective drawings, Figures 5 and 6). And, finally, to do a weight/sizing assessment of the advanced technology/systems to the extent such comparisons would have validity (e.g., with/without synthetic vision and/or the removal of ground operating capabilities from such a system). In many cases the weight/sizing considerations are insignificant when and where advanced technologies are concerned. The more critical consideration is the increase or decrease in mission critical functionality. Hence, the final task which was to determine mission performance differentials between and among the concepts and combinations, became confounded. For example, a no nose-droop configuration (Concept A) is by definition also a Concept C vehicle since advanced technology in a complex system (viz. a SVS) is required. It is not practical to have a Concept A without including a Concept C as an essential element. Additionally, such a vehicle (e.g., Concept A/C) is also independent of the far forward cockpit location, either side-by-side or tandem.

MISSION PERFORMANCE STUDIES (Task 12.5)

The mission performance studies that were conducted for Concept C (in combination with Concept A as indicated above), in accordance with Task 12.5, proved to be the singular most substantive area of investigation. A no nose-droop configuration that has limited external visibility and uses a technically and operationally viable synthetic vision system is a Category IIC (zero-zero visibility) all-weather air vehicle on every flight, by definition. This being the case, the nominal fuel reserve standards that specify a minimum of six-percent (6%) block fuel, with a flight to an alternate landing site 150 miles away at 1500 feet, and holds for 30 minutes, was considered to be excessive for the IISCT. Therefore, the fuel reserves were simply reduced to six-percent of the block fuel in order to provide for any reasonable contingency other than weather; which was no longer considered to be a factor because of the inherent Category IIC capability of the SVS-equipped airplane. In addition to the lower takeoff gross weight (TOGW), made possible through elimination of a droop-nose, substantial reductions in fuel reserves improved operating efficiencies, increased range and/or payload and, minimized emissions. The six-percent reserves also provides an adequate range in the event a diversion to an alternate destination is required. Using the six-percent reserve, the range to any landing site becomes a joint function of altitude/distance/time from touchdown; based on when and where notification to divert is received.

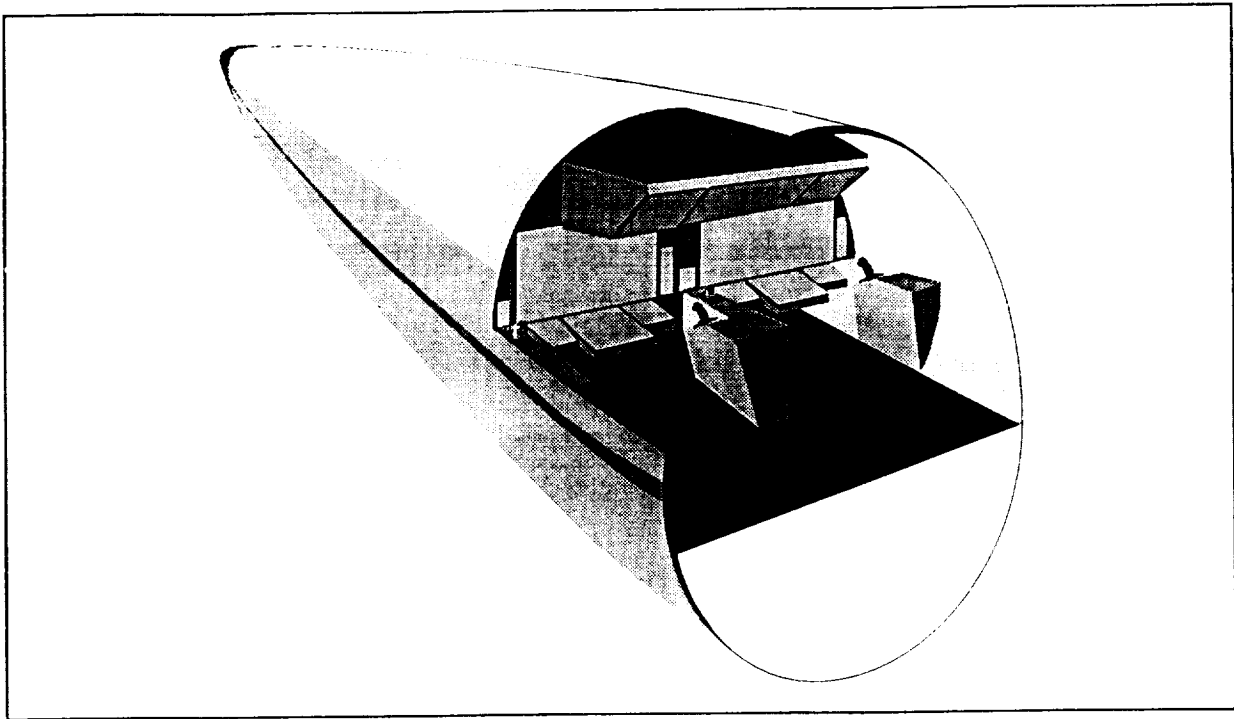


Figure 5. Side-By-Side Seating Arrangement

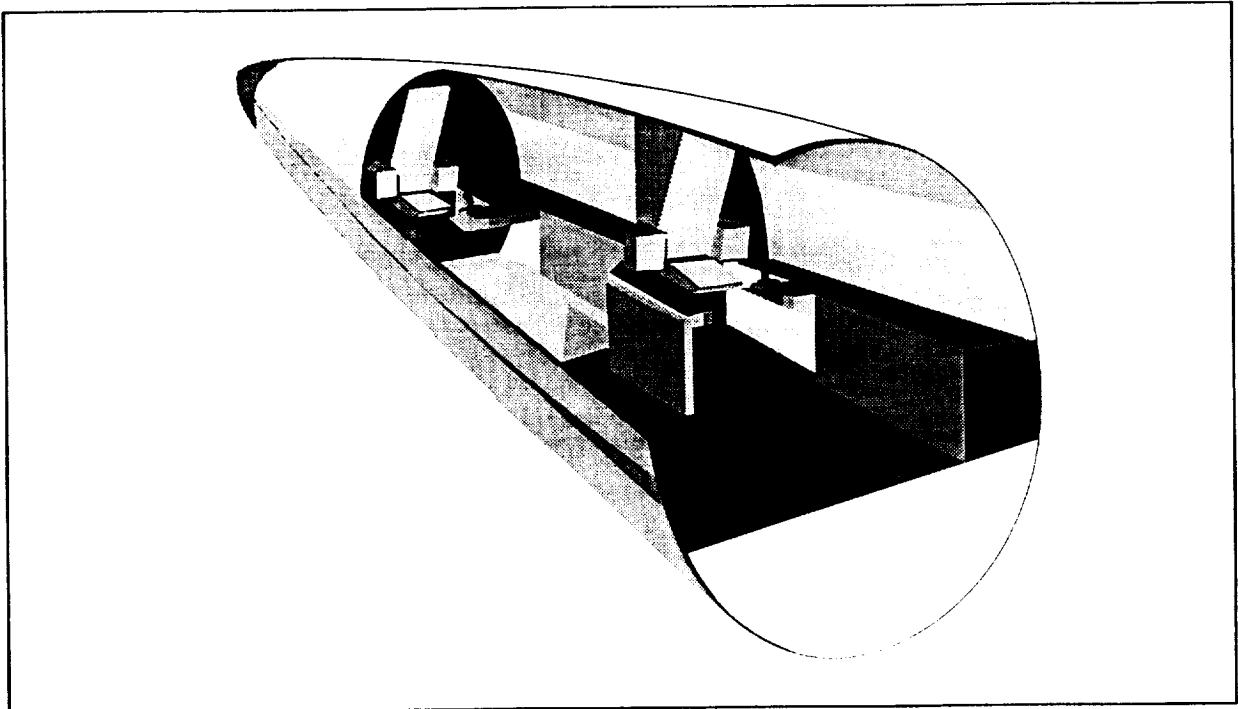


Figure 6. Tandem Seating Arrangement

OPERATING ECONOMIES (Task 12.6)

In evaluating the benefits in overall operating economies, the far forward tandem cockpit arrangement proved to be an interesting concept. The farthest forward location was 96 inches in front of the passenger compartment which provides for approximately three additional rows of economy passenger seating; thus potentially increasing the revenue generating capacity. This is, of course, assuming a 32 inch seat clearance for economy class. Various other combinations of seat mixes between first class, business, and economy are also possible depending on different clearance requirements (e.g., economy: 31"-34"; business: 38"-42"; and first class: 60"-62"). Another option, that may be more desirable than increasing passenger loading, would be to downsize the entire aircraft. This would improve both the operating economies and the environmental acceptability--factors that may have greater long-term benefits than the incremental gains in revenues. However, the investigation of such an option was beyond the scope of this effort.

Additional Assessments -

Additional economic and environmental enhancements based on performance improvements were also assessed for:

- Advanced communication/navigation/surveillance (CNS) systems - Based on global satellites network (GNSS) and Air Traffic Management (ATM) systems proposed for 2005, when the HSCCT enters the inventory, it has been estimated that Atlantic routes could save as much as 2-3% and Pacific routes 3-5% due primarily to improved efficiency in handling, routing, and managing in air traffic through dynamic flow control and closer-interval separations into the terminal areas.
- Operational towing - Utilizing towbar-less tractors and the new capabilities of Airport Surface Traffic Automation (ASTA) the HSCCT can be transported to and from departure/arrival gates and active duty runways with resulting reductions in fuel burn, as well as ground based emissions.
- Crew complement - The workload projected for a two-person crew could well exceed safe operating levels given the advanced technologies and complex systems required to adequately manage the unique supersonic requirements such as noise abatement, sonic boom, and environmental emissions monitoring. If crew monitoring and control burdens cannot be adequately alleviated through system integration and/or sophisticated human-centered automation, a third crew position could be required, representing approximately 25% increase in operating costs, which would represent a major blow to the economic viability of the HSCCT.

The quantitative results of these economic benefits and the environmental impacts are summarized in the following section of the report, both in the terms of percent savings and/or cost avoidances across an entire HSCCT fleet. This summary, attempts to quantify the impact on operating costs annually across an entire HSCCT fleet. These areas are the major indices utilized by the airlines to estimate the economic viability of a specific aircraft to serve their route structure and, hence, will ultimately affect their buy/no buy decision pertaining to HSCCT purchase.

FINDINGS AND RECOMMENDATIONS

FINDINGS

Concept A - No Nose-Droop -

The initial task under Concept A was to develop a special droop-nose configuration for comparison against the baseline vehicle, which had no nose-droop, and to provide a basis for assessing its size/weight and performance penalties. The droop-nose configuration (Figure 7) required the nose section to be reduced in length by 100 inches in order to accommodate over-the-nose forward vision requirements for approach and landing -- even when the nose was drooped to the full down position of 20°. The shortened nose section caused a significant blunting of the forward fuselage, resulting in a substantial increase in the wave drag from 21.3 to 22.9 drag counts at Mach 2.4. Such increases would have a major negative impact upon the vehicle's resized operator's empty weight (OEW), takeoff gross weight (TOGW) and performance as well as its economics.

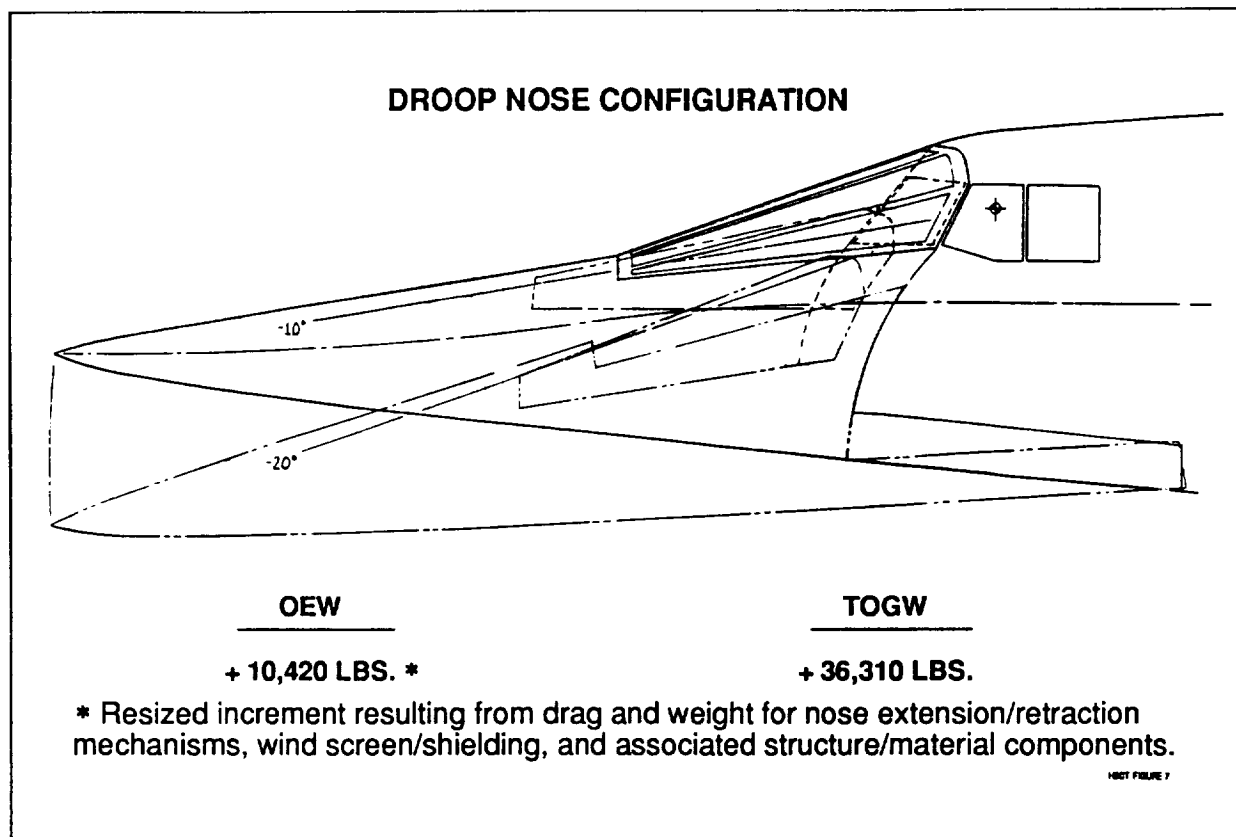


Figure 7. Droop-Nose Penalties

The combination of these negative effects of a droop-nose on the HSCT substantiated the validity of the "no nose-droop" configuration as a baseline.

The primary focus of Concept A, however, was the no nose-droop configuration and the associated enabling technologies required to support such a concept; consisting primarily of a Synthetic Vision System (SVS). As outlined in Table VI, these technologies included a suite of multi-spectral sensors, data processing/sensor fusion capabilities and large screen display media, all integrated through a high-speed multi-processor avionic bus architecture which included communication, navigation and surveillance, and a digital terrain data base. The estimated weight, volume, power, and costs, as indicated in Table VI, show that those technologies which are uniquely SVS are predominantly the sensor suite consisting of visual and infrared cameras and the millimeter wave radar. These components account for only about 80 pounds of the total flight deck/avionics weight of 5,057 pounds or less than 2 percent of the total. The costs are only slightly over \$200,000 or about 6%, however, this does not include the system development costs for synthetic vision which could well exceed 50 million dollars.

ELEMENTS	WEIGHT (POUNDS)	VOLUME (CUBIC FEET)	POWER (WATTS)	COST (DOLLARS)
INTEGRATED CORE PROCESSOR				
8 - ARINC 65X COMPUTERS	444	11	1800	400000
1 - MASS MEMORY (including ELS)	55	2	160	100000
INTEGRATED CREW STATION				
8 - AMCLD DISPLAYS	168	4	160	80000
2 - DATA ENTRY SETS	40	1	20	20000
8 - FLIGHT CONTROLS	160	4	20	16000
2 - BACKUP DEVICE SETS	40	1	40	2000
1 - INTERCOM FOR ALL	100	3	100	5000
INTEGRATED PASSENGER STATIONS				
300 - PASSENGER TERMINALS	2100	50	6000	300000
1 - SERVICE LOCAL AREA NETWORK	100	3	100	100000
INTEGRATED COMM/NAV/D SETS				
2 - ICNIARS	110	4	100	100000
1 - ANTENNA INTERFACE UNIT (INCLUDES ALL COMM. NAV. IDENT., DGPS, ETC.)	110	4	100	100000
INTEGRATED SENSOR SVS SUITE				
12 - VISUAL CAMERAS	*24	1	96	12000
2 - INFRARED CAMERAS/COOLING	*16	1	400	100000
2 - MWM SENSORS	*40	2	200	100000
1 - X-BAND MMIC ARRAY RADAR (INCLUDES ALS MODES & ACTIVE/ PASSIVE WEATHER)	50	2	2000	400000
4 - RADALTS	40	2	100	80000
2 - TCAS EQUIVALENTS	20	1	100	10000
INTEGRATED FLIGHT CONTROL SYSTEM (NO ACTUATORS INCLUDED)				
4 - STABILITY & CONTROL COMPUTERS	160	4	800	160000
4 - ACTUATOR CONTROLS COMPUTERS	160	4	800	160000
4 - AIR DATA/IRS/GPS/OTHER	200	8	800	160000
4 - MASS & CG COMPUTERS	80	2	160	80000
INTEGRATED CAWS SYSTEM (USES CORE PROCESSOR ABOVE)				
2 - FIRE WARNING SYSTEMS	110	2	100	10000
1 - PROXIMITY SWITCH SYSTEM	40	1	500	20000
INTEGRATED AIR VEHICLE MANGMT SYS. (USES CORE PROCESSOR ABOVE)				
10 - DUAL VEHICLE CONTROLLERS (NO ACTUATORS, PUMPS, GEN., PACKS, GEAR, ETC., INCL.)	500	10	1000	500000
2 - BIT SYSTEMS	80	2	80	40000
2 - RECORDER SYSTEMS	110	4	1000	40000
GRAND TOTAL	5057	133	16636	3,085,000
* Synthetic Vision System (SVS) unique components				HSCT-TABLE VI

Table VI. HSCT Avionics Suite



By far the overwhelming cost/economic benefits associated with the no nose-droop configuration and its synthetic vision system, results from the enhanced operational capabilities and attendant flexibility derived from the all-weather Category III operations and the associated reductions in fuel reserves. These impacts are assessed in conjunction with Concept C since the advanced technologies/complex systems for crew monitoring and control are inextricably intertwined with such all-weather capabilities, even though it is Concept A's lack of adequate external visibility which dictates an inherent Category IIIC (i.e., zero-zero) vehicle.

Concept B - Far Forward Cockpit Location -

This concept focused on two major options; 1) a conventional commercial transport side-by-side seating arrangement, and 2) an unorthodox tandem seating arrangement. The first was severely limited in the extent to which forward movement was possible due primarily to the conical shape of the nose and the need for separation clearance between crew positions. The second option sought to negate or avoid such constraints by aligning the crew fore and aft, with a slight offset both laterally and vertically. The vehicle size and weight were not assessed for such configurations, however, a considerable differential could be realized if the forward movement was converted to additional passenger seating. These results are summarized in Table VII.

Side-by-Side Seating

The side-by-side configuration allowed for a forward movement of the crew station of no more than 32 inches. This limit was a combined function of the DEP separation and the overhead/sidewall clearance. The 32 inches would permit one (1) additional six-across row of seating in economy class. No other seating options were possible because both first class and business require clearances in excess of 32 inches (e.g., first class: 60"- 62"; business: 38"- 42").

FAR FORWARD COCKPIT LOCATION				
	SIDE-BY-SIDE - Forward Movement of 32" - Maximum Increase of One Row (6 Across) in Economy			
				
	CURRENT	POTENTIAL ADDITIONS ()		
	BASELINE	1st CLASS	BUS. CLASS	ECON. CLASS
FIRST CLASS	28	36 (+8)	28	28
BUSINESS	86	84 (-2)	96 (+10)	86
ECONOMY	186	188 (+2)	188 (+2)	200 (+14)
TOTAL	300	308 (+8)	312 (+12)	314 (+14)

HSCT-TABLE VII

Table VII. Far Forward Cockpit Location

Tandem Seating

The tandem configuration allowed for the crew stations to be moved forward a total of 96 inches which provided for a wide range of options for additional passenger seating. These consisted of various mixes across the three fare classes, ranging from up to 14 economy class through 8 additional first class, with various combinations in between.

The economic advantage of a far forward cockpit location, however, would not be to increase the passenger carrying capacity beyond the baseline of 300, but rather to downsize the vehicle which would not only enhance economics through improved operating efficiencies by reducing fuel burn and hence engine emissions. Unfortunately, such downsizing efforts were beyond the scope of this effort.

Concept C - Advanced Technology and Complex Systems

This concept involved various economic and environmental assessments derived from a host of advanced technologies supporting all-weather (Category III) capabilities with attendant fuel reserve reductions and a variety of complex systems requiring extensive crew monitoring and control within a global ATM system.

"In the U.S. unscheduled delays* [annually] consume the equivalent of a fleet of 500 airplanes."³ In Europe one in five flights are delayed at a cost of \$3 billion per year. The cost of ATC system delays world wide has been estimated at \$10 billion. Hence, the proposed future air transportation system of satellite-based communication, navigation, and surveillance (C/N/S), although no panacea, has potential to improve a worsening global airport/airways congestion situation. HSCCT with its Category III all-weather capabilities and advanced C/N/S suite of on-board systems, will be a major beneficiary of such technology upgrades and serve as part of the solutions.

All-Weather Operational Enhancements

A major impact of the all-weather Category III capabilities results from a considerable increase in operational flexibility including expanded takeoff/land options. Initially, all-weather takeoff allows each flight to be launched, on time, without any delay. More importantly, however, is the greatly enhanced landing options that are available. Because the HSCCT has capabilities which are autonomous of the arrival site's landing aids, approaches to Category III approaches can be made to Category I and II airports when the weather at those fields are below minimums. This dramatically increases the dispatch reliability and on-time arrivals, all of which significantly enhance operating economics; to say nothing of passenger attitudes.

This translates into sizeable increases in operating flexibility and efficiency. Weather related diversions and cancellations can be dramatically reduced, if not eliminated, and enhanced on-time arrivals through delay reduction/avoidance represents a substantial cost saving annually across an entire fleet. A cost/benefit model for assessing the impact of such enhanced operating conditions has estimated \$200,000 average cost savings annually per aircraft, or approximately \$188 million weather related cost avoidance across an entire HSCCT fleet. A dramatic impact from all-weather capabilities to say the least!

* unscheduled delays - > 15 minutes beyond original departure time, of which, approximately 65% are weather related.

Fuel Reserve Reduction

Far and away the most significant impact was that associated with the reduction in fuel reserves based on the HSCT being an inherent all-weather vehicle; with Category IIIC (zero-zero) capabilities. Approach and landing guidance and control is provided through synthetic vision, augmented by updated landing aids and precision satellite navigation. This capability enables the HSCT to operate independent of the weather and, hence, allows for a reduction in fuel reserves which are provided primarily for weather related contingencies and delays (e.g., alternates and/or holding patterns). By retaining only six percent (6%) of the block fuel as reserves, while eliminating the additional fuel required to reach an alternate 150 miles away at 1500 feet, and hold for 30 minutes. The baseline HSCT would still possess sufficient fuel to cover any conceivable contingency, with adequate safety margins, while allowing for in excess of 155,000 pounds *reduction* in maximum takeoff gross weight (MTOGW). (Table VIII). Incidentally, when enhanced weather forecasting, two way data link communications and dynamic enroute/terminal area flow control are considered, the range extension for alternate airports could double if nominal enroute descent profiles are utilized.

REDUCED FUEL RESERVES	
• OLD FUEL RESERVES: (71,000 Pounds)	
a) 6% BLOCK FUEL (45%)	
b) 200 NM ALTERNATE (26%)	
c) 1/2 HOUR HOLD @ ALTERNATE (29%)	
• NEW FUEL RESERVES: (27,700 Pounds)	
a) 6% BLOCK FUEL (100%)	
WHAT ARE THE ALTERNATE OPTIONS WITH THE NEW RESERVES?	
a) ALTERNATE FROM SUPERSONIC CRUISE	⇔ 550 N MI (Supersonic Cruise)
b) ALTERNATE FROM SUBSONIC CRUISE	⇔ 470 N MI (at 43,000 feet)
c) ALTERNATE FROM FINAL APPROACH	⇔ 330 N MI (Climb/Subsonic Cruise)

HSCT-TABLE IX

Table VIII. Reduced Fuel Reserves

The economic impact* is substantial due largely to aircraft downsizing and reductions in takeoff gross weight (TOGW) which enhances overall operating efficiency; due to the need to carry less (i.e., reserve) fuel. All of these contribute to significant reductions in total fuel burn (approximately 49 billion pounds less) with attendant reductions in operating costs as indicated in Table IX.

* Economic assessments were made based on mature fleet size of 942 aircraft by the year 2015 and a supersonic global route structure including 284 city pairs.

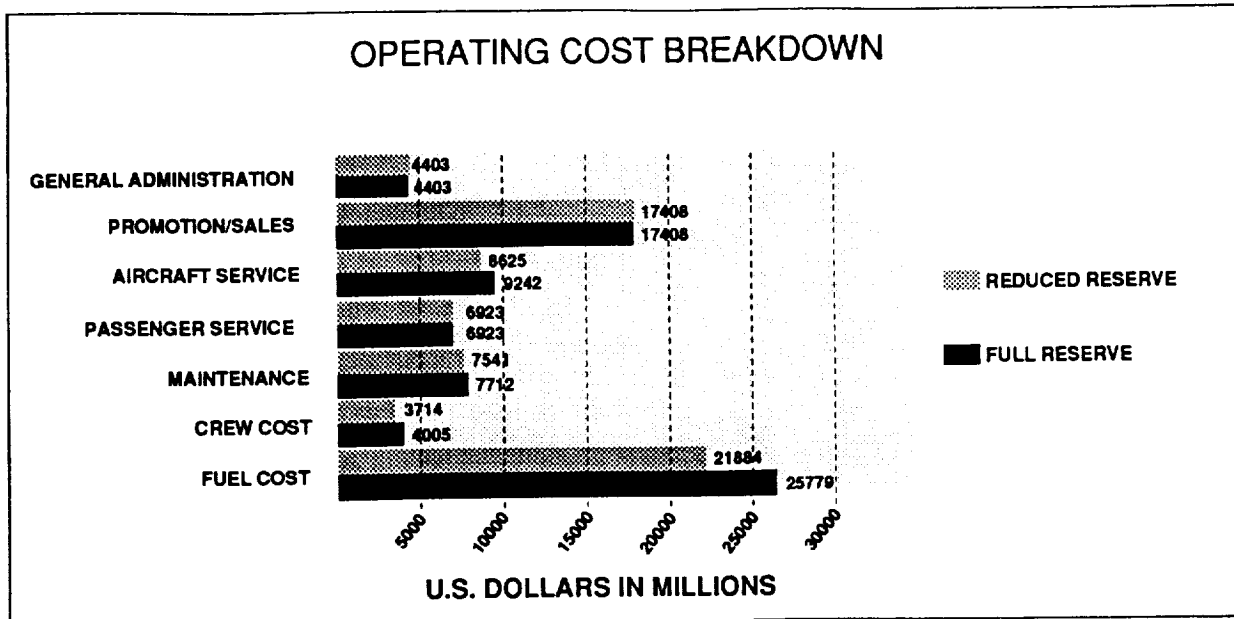


Table IX. Reduced Operating Costs

The impact of such enhanced operating performance on each of the aircraft in the fleet is shown in Table X. As indicated, not only are the costs reduced (-9%), but the profit is substantially increased (+18%); which represents a sizeable benefit contributing to aircraft value and the overall economic viability of the HSCT. Additionally, the reductions in fuel burn (43 billion pounds per year) represents approximately 15% reduction, globally, in engine emissions which represents a significant improvement in environmental acceptability. Hence, the combination of enhanced economic and environmental impacts of the fuel reserve reductions are a major positive influence on the HSCT baseline.

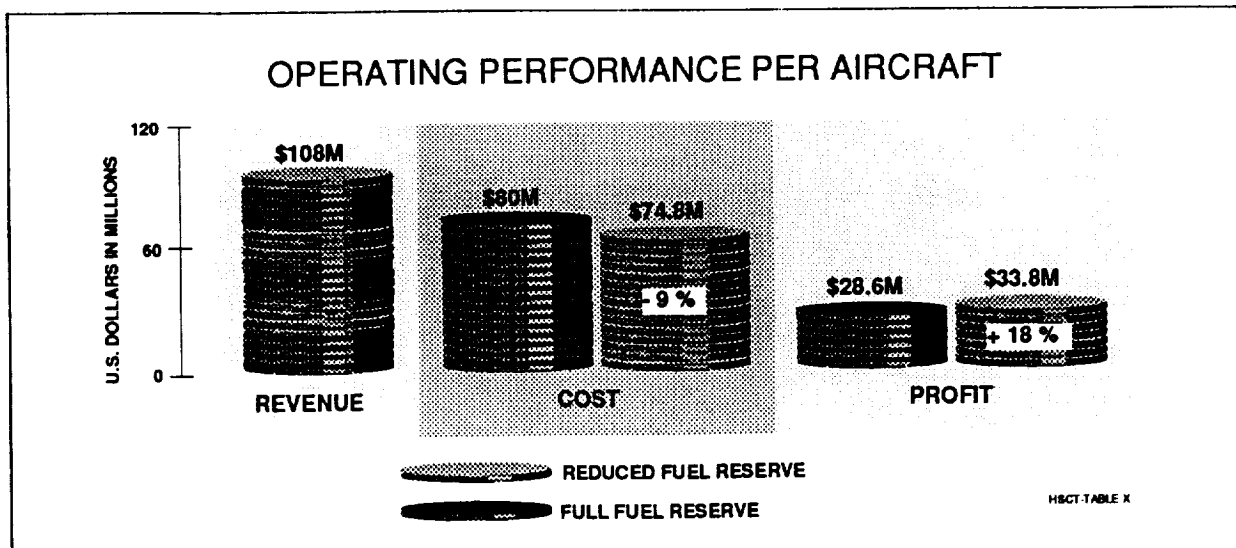


Table X. Operating Performance Per Aircraft

Advanced Systems/Technologies

A final area assessed, under Concept C, was the combined effect of a plethora of advanced flight deck systems and technologies that the crew must monitor and control in the operational environment of the 2005 era. That environment will include two-way air/ground data linking, precision satellite-based navigation and automatic surveillance as well as a host of ground-based automatic air traffic management systems. The net effect of all of these technology innovations will be to drastically change the way air traffic is managed and controlled leading ultimately to a greater improvement in effectiveness and efficiency.

One of the major U.S. carriers has estimated that on trans-oceanic routes, particularly those across the Pacific, an extra 10,000 pounds of fuel is loaded on-board, of which 6,000 pounds is never burned, simply because of flight plan routing (e.g., user preferences) uncertainties; resulting in "at least 5% of our operating cost, on an average, is now wasted".⁴ That same carrier has also estimated that they "could save 2-3% of fuel burned on an Atlantic crossing"⁵ through user preference routing for optimal wind conditions, cruise climb profiles, and reduced separations made possible by satellite precision navigation (GPS), surveillance (ADS), and data link. Estimates are that both lateral and vertical separation might be halved. The economic impact of such changes due to reduced fuel burn are shown in Table XI. This reduced fuel burn would have an equivalent beneficial effect on the environment by reducing emissions some 3-5%.

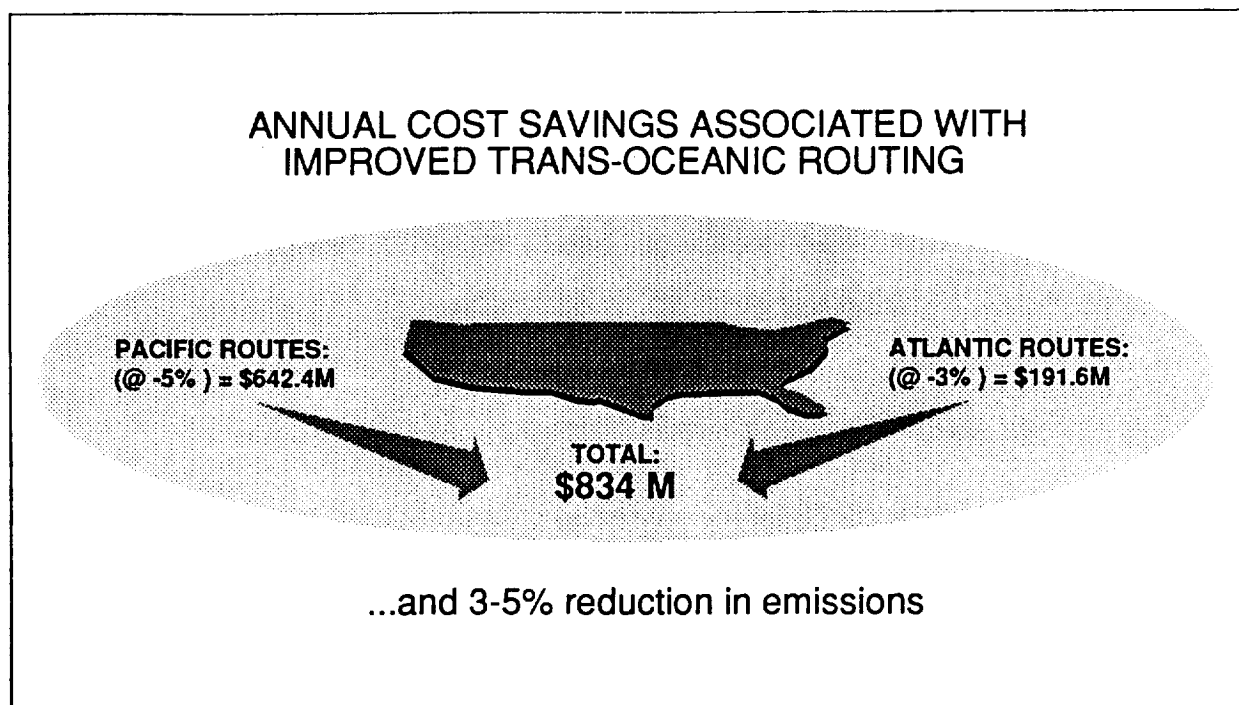


Table XI. Advanced Systems/Technologies - Economic Impact

Operational towing -

Operational towing refers to a concept, utilized in Europe for a number of years, in which towbar-less tractors are used for "towing aircraft relatively quickly from gate to runway for

take-off. The saving in fuel alone would be very considerable" ... as well as... "reduced environmental impact -- less noise and aircraft engine emissions"*

In the baseline HSCT mission performance analysis, the taxiing segment to takeoff spans 12 minutes from departure gate to brake release on the active runway. During the aircraft taxi, 2311 pounds of fuel is used and approximately 3.466 pounds of nitrogen oxide (NO_x) plus an additional half again as much (e.g., 1165 pounds of fuel, 1.733 pounds of NO_x) on return taxi from runway to arrival gate. This amounts to a net saving per cycle of 3476 pounds of fuel resulting in an avoidance of 5.2 pounds of NO_x emission.

Based on these estimates, the projected impact on one of the high intensity HSCT airports where environmental concerns are the greatest, such as Los Angeles International (LAX), indicates that NO_x emissions could be reduced by 690 pounds; hydrocarbons (HC) by 5,800 pounds; and carbon monoxide (CO) by 12,950 on a weekly basis. The amounts of almost 18 tons less NO_x, 150 tons less HC, and 300 tons less CO each year which would represent a significant positive impact on the environment (Table XII).

ENVIRONMENTAL EFFECTS OF EXHAUST GAS EMISSIONS AVOIDED*			
	NO_x	POUNDS HC	CO
Per T/O	3.466	28.941	65.022
Per Cycle	5.213	43.528	97.795
Per Week (LAX)	690	5,800	12,950
Tons Savings/Year	18	150	300
Economic benefits as a result of reductions in fuel burned (in pounds)			
2311/T/O	3476/Cycle	460K/Week	24M/Year
Saving 3,796,825 gallons @ \$.60/gal. or \$2,278,095 per year			
Annual savings at LAX representative of major HSCT hub (HSCT is approximately 20% of mid/long range fleet)			
* Data based on ratios of HC and CO to NO _x reductions in exhaust gases achieved by one European carrier annually over their entire wide body fleet.			

Table XII. Operational Towing: Environmental Effects/Economic Benefits

While not directly involving the crew in ground control, the concept none the less would require crew monitoring of transit to and from the gate and hence, would represent one of the advanced technologies/system which could enhance HSCT operability.

Additionally, operational towing may well represent a technology which could be utilized to offload a segment of crew workload which as indicated is an area of growing concern.

* Taken from paper by A.W. Lock, BAA Plc entitled "High Speed Towing of Aircraft", May, 1990.

Crew Complement

Upon review of all of the advanced technologies and complex systems needed to support a droop-less HSCT concept, with a synthetic vision system for all-site Category III operations, one is struck by the challenge facing a flight crew of only two. The narrative mission scenarios (Appendix J and K) prepared for the takeoff/departure and approach/landing mission segments and the associated flight profiles and activity timelines dramatically capture the unique nature and level of intensity on the flight deck; reflective of the crew's workload requirements. Had additional time and resources been available, these profile/timelines would have been further analyzed and a qualitative workload metric would have been developed to assist in assessing crew and/or automation concepts required to manage workload. Unfortunately, these efforts were prematurely terminated by funding constraints.

One is left, however, with the uneasy impression that the current levels of system complexity and automation, along with a number of operational constraints imposed to meet environmental restrictions (e.g., noise abatement procedures) represent marginally acceptable workloads and safety of flight. The solution is to expedite and/or intensify system automation technology development addressing unique HSCT system integration and crew interfacing issues. In the absence of such efforts, adding a third crew member could be the only alternative to excessive workloads.

This alternative as indicated in Table XIII would have dire consequences on HSCT economics. The 26.5% increase in operating costs, due to a third crew member, would almost certainly destroy operating profitability and, hence, decimate the economic viability of the HSCT.

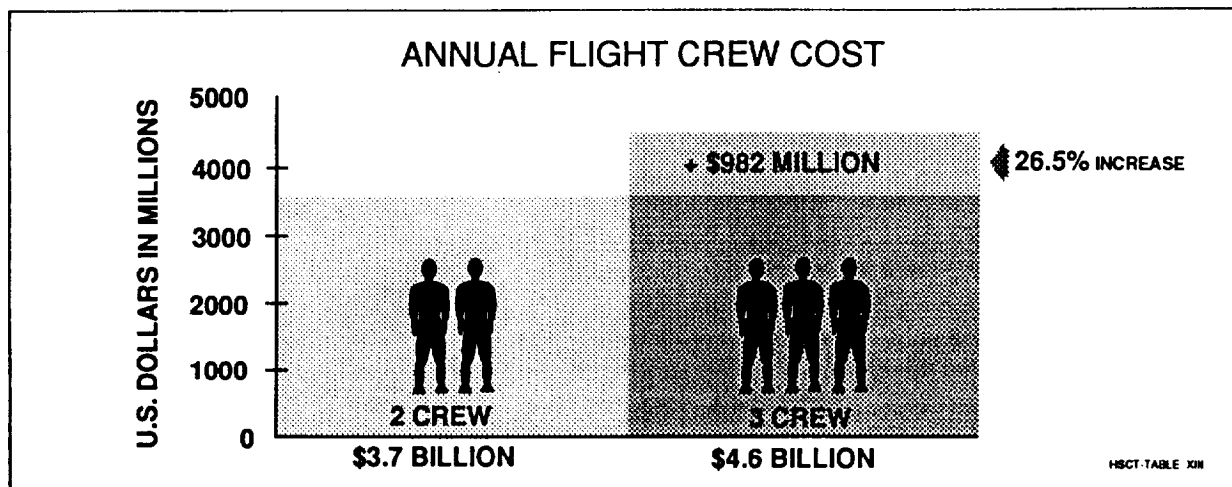


Table XIII. Flight Crew Cost Per Fleet

The inescapable conclusion is that, collectively, the advanced flight deck configuration effects represent a sizeable and significant impact on both HSCT economics and environmental acceptability

RECOMMENDATIONS

A general recommendation would be to continue funding the flight deck efforts throughout the Phase I system studies and not wait until Phase II as it is currently planned. The prime reason for the continuation of the effort is that it has become clear that the unique requirements of the HSCCT and the advanced flight deck technology integration required to achieve the operational capabilities essential for economic viability necessitate immediate and escalated technical development efforts to ensure *technology readiness* within the next decade. This criticality is substantiated by the following key factors:

- Synthetic vision is mandatory to the no nose-droop concept
- Flight deck development will not be derivative in nature
- Systems integration and automation levels required to manage a two-crew workload are unprecedented in commercial transports
- Flight deck/ATM integration is a major, unmet challenge

An initial and specific immediate recommendation would be the formation of a NASA/Industry Working Group on Synthetic Vision to ensure that all of the technologies, including sensors, processors, and displays are progressing on schedule and each have the capacity to be integrated into a safe, reliable, certifiable flight system, well before Engineering Authority to Proceed (EATP) at the end of CY 1996. This action would ensure that the no nose-droop configuration remains viable.

As proposed in the joint NASA/Industry Technology Development Plan, currently being coordinated, synthetic vision is assumed to be a NASA HSCCT technology development area, just as the flight deck simulation facilities and flight test vehicles are considered key technical resources for the current High Speed Research program. If such assumption is not valid or appears unrealizable, then both parties must be made aware of this so that alternative plans can be developed and the resources reallocated in order to preserve schedule integrity.

A second, and equally critical, recommendation would be to accelerate and intensify the technology development efforts that relate to *flight deck automation*. This area remains a major challenge both in the terms of man-machine integration and safety of flight issues. The level of systems integration and systems complexity (e.g., integrated flight-propulsion systems and flight control high-lift devices) in addition to time criticality of sophisticated flight profiles (e.g., noise abatement profiles) and configuration changes (e.g., high-lift device retraction/thrust modulation schedules) dictate types and levels of automation that have not previously been attempted. The degree of system autonomy and/or crew involvement as well as the appropriate crew interface and information management, all require pioneering efforts. The absence of such efforts early in the development program, historically, has resulted in design flaws and error potentials which have plagued "glass cockpit" automation innovations and has lead to "second guessing" throughout the life of the vehicle.

The areas of synthetic vision technology readiness and high levels of system integration/automation are HSCCT specific, however, there are a number of additional flight deck issues that both future subsonic and supersonic transport share. These should be combined into a unifying and coordinated research and technology development effort in such areas as:

- Integration of a global satellite network (GNSS) for advanced communication/navigation/surveillance (CNS) and their flight deck components compatible with future Air Traffic Management (ATM) systems (e.g., ATN/ATIS, GPS/MLS, ADS).
- Appropriate crew interface and function compatibility for the above flight deck components with existing and/or future flight deck technologies (e.g., GPWS, TCAS, ELS/OMS, FMS) to provide optimal information transfer, human error minimization and enhanced situational awareness.
- Improved flight deck/ATC integration throughout transition to Advanced Automation System (AAS) in which Automated Enroute ATC (AERA) and Terminal ATC Automation (TATCA) as the backbone, will provide automated airspace management and traffic flow control to increase capacity and improve efficiency without compromising safety.
- Monitor and track development of new innovative aviation technology programs such as wake vortex alerting and avoidance (IWVS), wind shear/microburst detection and tracking (LLWAS) and terminal radar upgrading (TDWR) as part of the automated weather services (AWOS) to digitally/electronically display real-time weather in the cockpit, in addition to the Airport Surface Traffic Automation (ASTA) to enhance safety in low visibility ground operations using the same cockpit technology.

What is being advocated is the adoption of a comprehensive, totally integrated systems approach for advanced flight deck development, as outlined in Figure 3, to address emerging technologies, systems integration, and performance optimization for commercial transports. This will ensure the maximization of return on investment and the capture of synergy of commonality, for both subsonic and supersonic vehicles sharing the same operational requirements and environment.

As indicated at the outset, future flight decks present many challenges, but if responded to early in a systematic and orderly manner, the benefits and payoffs can be substantial for a safer, more efficient air transportation system able to respond to increasing capacity demands of the 21st century.

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APPENDIX A

The NAS and the HSCT (The National Airspace System for the High Speed Civil Transport)

In the NAS of the future, flight paths desired by users will be accepted on a regular basis, flight operations will be accommodated with a minimum of constraints and dynamic flow management will reduce delays, increase capacity and enhance safety throughout the system; all with the highest practical fuel efficiency. Advanced technology automation, communications, navigation, and surveillance systems will be utilized by both the ground based and airborne elements to increase productivity and reduce workload of controllers and pilots alike; without compromising system safety.

The Advanced Automation System (AAS), Automated EnRoute Air Traffic Control (AERA), and related technologies of ground-air data linking and satellite navigation will improve traffic management throughout the airspace system and enhance user efficiencies. Supporting these hardware and software resources will be surveillance capabilities provided by Mode S data link and an improved radar network which will provide more accurate data for improved flow management and control. Weather projections will provide improved sensor detection and real-time dissemination of information contributing to delay reductions while reducing procedural restrictions operating in to and out of terminal and en route airspace.

The NAS controls departures and arrival rates at all airports through the Central Flow Control Function (CFCF) of the Air Traffic System Command Center (ATSCC). A new National Airspace Management Facility (NAMFAC) currently in planning will house an extensive Modeling and Analysis facility, the National Weather Service Central Flow Weather Service Unit (CFWSU) as well as the CFCF and enhancements for an improved efficiency, reduced delays, enhanced and expanded user service and increased responsiveness to user requirements.

The National Airspace Management facility is being designed to provide improved data for management, analysis, and airspace use design along with monitoring and control algorithms to better manage traffic flow. Airspace will be more efficiently used through improved departure spacing, arrival sequencing and en route spacing programs to better integrate and control flow management. En route airspace automation will detect potential violations of separation standards, generate conflict alert/resolutions, and adjust flow patterns.

Accommodations of increased demand, reduction in ATC-induced delay, increased provisions of user-preferred route/altitudes, and enhanced delivery of weather services are the main objectives of the NAS automation currently being developed. Automation of the en route traffic planning and management will improve traffic flow efficiency, minimize delays, and deliver aircraft to the terminal area in a sequence that will increase acceptance rates. To minimize delays, improvements will be achieved by feeding multiple runways with multiple aircraft streams taking into account uncertainties in demand and capacity resulting from such variables as wind, weather, traffic mix, and flight and departure times.

Besides delay reductions, NAS users will experience enhanced operational efficiencies through the greater availability of user-preferred routes and altitudes from AAS and AERA capabilities. Together they will reduce the need for altitude and route procedural restrictions, currently needed to ensure safe aircraft separation, which will result in time savings for passengers

and greater efficiency in operations; resulting from reductions in fuel requirements and other aircraft operating costs.

All NAS users generally agree on the need for extended communication, navigation, and surveillance services, as well as improvements in weather services, to improve the safety and efficiency of their operations. Each wants the flexibility to operate with minimum constraints within navigable airspace and access to airspace and/or airports should be limited only if it disrupts the safe, orderly, and expeditious flow of air traffic.

The air carriers in particular employ large, expensive jet aircraft equipment with sophisticated avionics in which schedule reliability is of paramount importance. Hence, their special needs includes the ability to fly preferred, minimum-operating cost routes, on a routine basis, in which delays must be minimized and airspace access maximized. All weather operations and airport arrival/departure sequencing enhancements are crucial to achieving reliable, timely services in the future as traffic growth continues to expand.

Additionally, the expanded capabilities required to service the needs of the 21st century and beyond must be global in scope and based on internationally accepted standards. An excellent example is the International Civil Aviation Organization (ICAO) work on the Global Navigation Satellite System (GNSS), including the U.S.'s Global Positioning System (GPS) and the Soviet's GLONASS satellite navigation system. In addition, their Future Air Navigation Systems (FANS) concepts for communication, navigations, and surveillance (CNS) utilizing a global satellite network and air traffic management (ATM) systems for world wide operations over the next 20 years is increasingly gaining attention.

Such a global perspective is essential to the economic viability of the IISCT which is in essence an intercontinental air transport. For example, it has been estimated* that such capabilities as the Automatic Dependent Surveillance (ADS) via satellite could provide much better control enabling a reduction in lateral separation to 30 nautical miles from the current 60. The addition of GPS navigation might well allow a further reduction in lateral spacing to 15 NM and vertical separation could be reduced from 2,000 feet to 1,000 feet with GPS-provided altitude replacing the barometric altitude reference currently in use. These reductions in separation represent substantial fuel savings on routes, such as over the Atlantic, where track systems can funnel traffic to catch the optimum wind conditions. In fact, it has been estimated that reduced separations, combined with cruise climb profiles rather than step climb on an Atlantic crossing might well save 2-3% of fuel burned which represents a significant cost savings.

* "ICAO Delegates Back FANS Concept, Set Stage for Global Satellite Systems", *Aviation Week & Space Technology*, October 14, 1991, p. 36.

APPENDIX B

The Role of ASTA in Support of HSCT

The FAA currently has an Airport Surface Traffic Automation (ASTA) system under development designed not only to provide automated surface traffic management, integrated with other ATC automation systems, but to prevent the further escalation of runway incursions which has risen dramatically in recent years. For example, runway incursions rose from 179 in 1988 to 249 in 1990, an increase of almost 40% in just two years. In addition from January 1990 through February 1991 there were three serious accidents, at major domestic airports, resulting in 43 deaths due to surface collisions. The purpose of the ASTA project in addition to surface safety enhancements is to reduce surface-related flight delays and increase the efficiency of flight operations on all weather conditions. In this context, the capabilities will enable the HSCT, which is a Category III aircraft by virtue of having no external visibility, to conduct surface operations safely regardless of the weather.

ASTA will develop new techniques for surveillance, communications, and automation on the airport surface. Initially, electronic surveillance of the airport movement area and approach/departure airspace will be obtained from the Airport Surface Detection Equipment (ASDE-3) and the Airport Surveillance Radar (ASR). Later a system for automatic control of surface guidance and stop bar lights will be added. The automatic processing needed to implement traffic management algorithms and coordination with other automated ATC systems will be developed, along with two-way data linking between the tower cab and the cockpit for surface traffic management and conformance monitoring. ASTA is planned to proceed in three overlapping phases.

Phase I will focus on safety enhancements by extending the radar-based capabilities of the Airport Movement Area Safety System (AMASS). AMASS will add automation enhancements to ASDE-3 to provide conflict alert algorithms enabling tower controllers to detect and prevent runway incursions/accidents. Digitally processed ASDE-3 target data will be converted into target data interfaces with Automated Radar Terminal System (ARTS-III) for conflict alert algorithms. Audible and visual alerts will be activated in the tower when runway incursions or other movement errors occur or appear imminent. Safety enhancements, include a system of automatically controlled runway entrance stop bars and taxiway guidance lights to help reduce airport surface movement errors.

Phase II will expand surveillance capabilities through development of a Mode S multilateration system. This additional surveillance information will provide positive identification of Mode S equipped aircraft and ground vehicles as well as permit identification tags to be added to ASDE displays; greatly improving the tower controller's ability to manage surface traffic. This phase will also implement traffic management capabilities for taxi management and departure sequencing including the ability to monitor compliance with assigned taxi routes.

Phase III will further expand Mode S to include two-way data link. In addition to delivery of surface data between the tower and the cockpit, this data link will also provide time-critical alerts directly to the cockpit in the form of safety messages as an additional means of implementing active taxi route guidance, displaying surface traffic, and upgrading conformance monitoring capabilities. Additionally, Phase III will provide the integration of airport surface traffic management functions with Terminal ATC Automation (TATCA) and other ATC automation systems.

In addition to ASTA, the Surface Movement Safety and Guidance project will develop improved navigation and guidance capabilities on the airport surface as well as alternative technologies for detecting and preventing runway incursions. Electronic cockpit displays providing surface maps and the position of the aircraft will also be developed. Additionally, airport design guidelines to simplify surface traffic operations and minimize the risk of runway collisions due to reduced visibility will also be formulated.

In summary, on the airport surface aircraft will use cockpit maps of the airport with assigned taxi routes superimposed, including intermediate clearance limits such as hold short points. The aircraft position on the map can be determined using GPS* and/or INS. The purpose of such a map display would be to improve situation awareness, aid ground navigation, and help the crew avoid any runway/taxiway incursions to or from active runway enroute to the gate. Additionally, data link communications will be utilized on airport surface for delivery of predeparture and taxi clearances as well as for guiding aircraft along their assigned taxi routes and monitoring their conformance. Signs and signal lights including sequenced taxiway centerline lights and stop bars will also supplement airport surface electronic guidance and surveillance by indicating the status of runway and taxiways. Data link will also provide alerts of impending incursions for both ground controller and flight crews alike.

All of these FAA R&D activities are currently scheduled for completion by the year 2000, which is compatible with the planned date for the HSCCT's entry into the operational inventory, in the 2000-2005 time frame. With the absence of any external visibility, the ability to conduct ground operations safely and effectively is of concern. Transit from gate to runway, or visa versa, whether under it's own power or under tow, would be greatly facilitated by these proposed technologies for enhanced safety under restricted visual conditions; to say nothing of totally blind taxi procedure.

Since these capabilities, however, are for the generic management of surface traffic, be it aircraft or ground vehicles, the potential viability of a tow tug concept may provide an attractive alternative. Such concepts are currently employed in Europe for environmental reasons (noise and emission control) in addition to the economic benefits of reducing fuel burn through the elimination of taxi. The ASTA capabilities, which include both visual and electronic guidance, may well support this less costly and simpler solution to ground operations than autonomous taxiing, since the tug would have access to visual aids not available to the HSCCT itself and may be a safer and more accurate means of transiting to and from the gate.

The technical feasibility and economic viability of the various alternatives and options will have to be explored in more detail and cost trade-offs examined. At the present, however, it does appear that autonomous ground operations via synthetic vision may not be an absolute requirement for the HSCCT by the year 2005.

* A recent Aviation Week & Space Technology (Oct. 14, 1991) describes an imaginative commercial concept utilizing differential GPS to display aircraft position in the cockpit on a very accurate (within 1 meter) digital airport map as well as alerting the pilot with an aural warning of potential hazards, such as approaching an active runway or nearing the edge of the taxiway.

APPENDIX C

HSCT Configuration Layouts

Background -

The original crew station configuration (i.e., two-man, side-by-side) resulted from studies and configuration recommendations coming from the Advanced Supersonic Transport (AST) concepts. Task Assignment 12, Advanced Flight Deck Configuration Effects of the HSCT, established guidelines for "...flight deck concepts and systems which permits safe and efficient HSCT operation using a two-person flight deck crew under the following conditions:

- (1) No nose droop
- (2) Far forward cockpit location
- (3) Advanced technology crew monitoring and control".

The original crew compartment location and side-by-side seating configuration is more *traditional* than *conventional* since this type of crew seating has been in the commercial transport for over fifty years. The unique requirements of the HSCT challenges many of the "traditions" of the commercial transport both in design and function. One of these challenges is to make the HSCT cost effective. Additional passenger occupancy could generate sufficient revenue to make each HSCT flight a profitable venture. The desire to have additional passenger space influenced the actions that are described in the following paragraphs.

Approach -

The approach began with a review of the forward fuselage drawings developed by Advanced Commercial Programs. This drawing provided dimensions and location of the two-person, side-by-side crew cockpit area in a far forward fuselage location. The drawing was reproduced to scale and constructed on a Macintosh workstation using a suitable graphics development software package. In this presentation, human manikins of typical anthropometry were installed using the cockpit interior dimensions given on the 1/20th scale flight deck front-end view.

The two-person, side-by-side arrangement does not permit any extensive relocation of the crew cockpit area considering the constraints on minimum overhead and lateral clearances as shown on the front-end drawing. Because

of these constraints, no relocation of the two-person, side-by-side cockpit configuration was investigated.

The side-by-side seating arrangement, with the instrument configuration that is being proposed for the tandem seating, is shown in Figure 1. The vertically-installed large screen display and the horizontal situation display, along with the two angularly-installed systems displays, are mounted in the same location relative to each crew position as in the tandem arrangement. Similar to the tandem arrangement, the side-by-side arrangement has individual throttle controls for each crew position. The limited space between each crew position does not permit installation of a control pedestal.

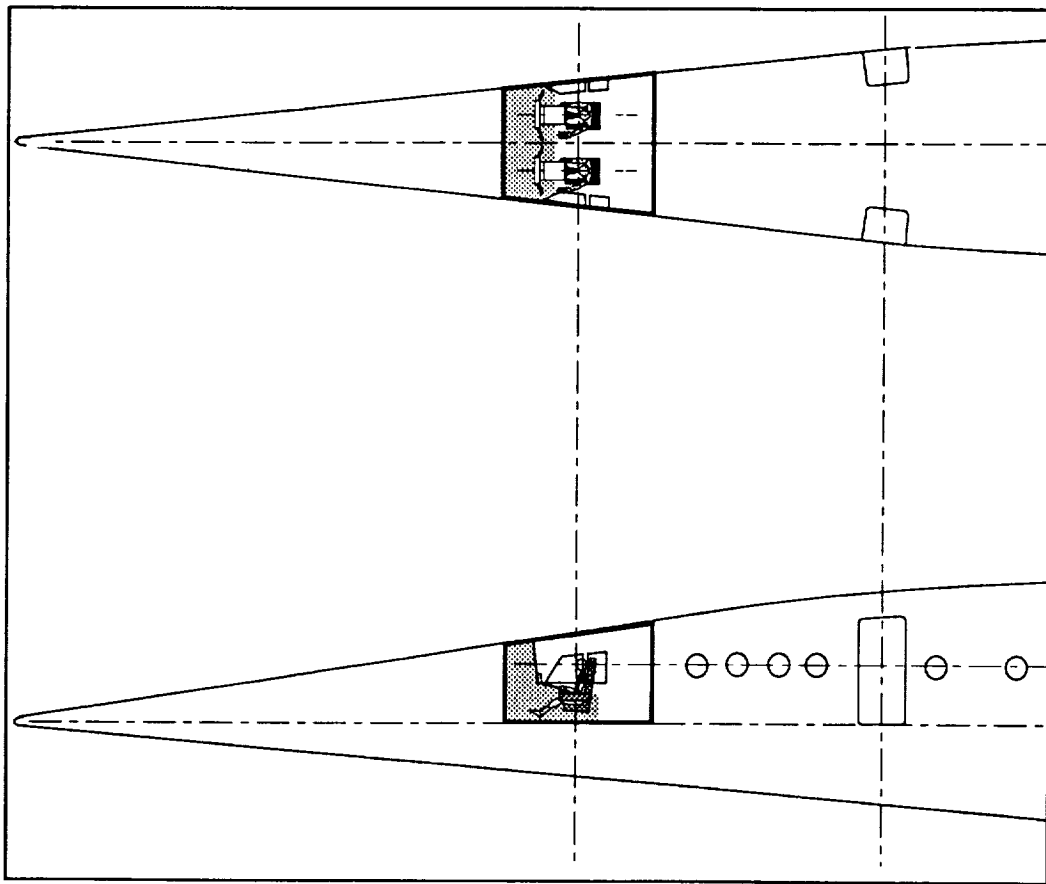


Figure 1. Original Side-by-Side Arrangement

In-Line Tandem Seating -

The first alternative to the side-by-side seating configuration was the in-line tandem seating (Figure 2). In this configuration, the constraint was the minimum overhead clearance for the forward crewmember. The in-line tandem seating configuration places limitations on the rear crewmember and his/her ability to have visual contact with the forward crew position. Also, ingress and egress of the forward position could have restrictions due to the location of the rear seat.

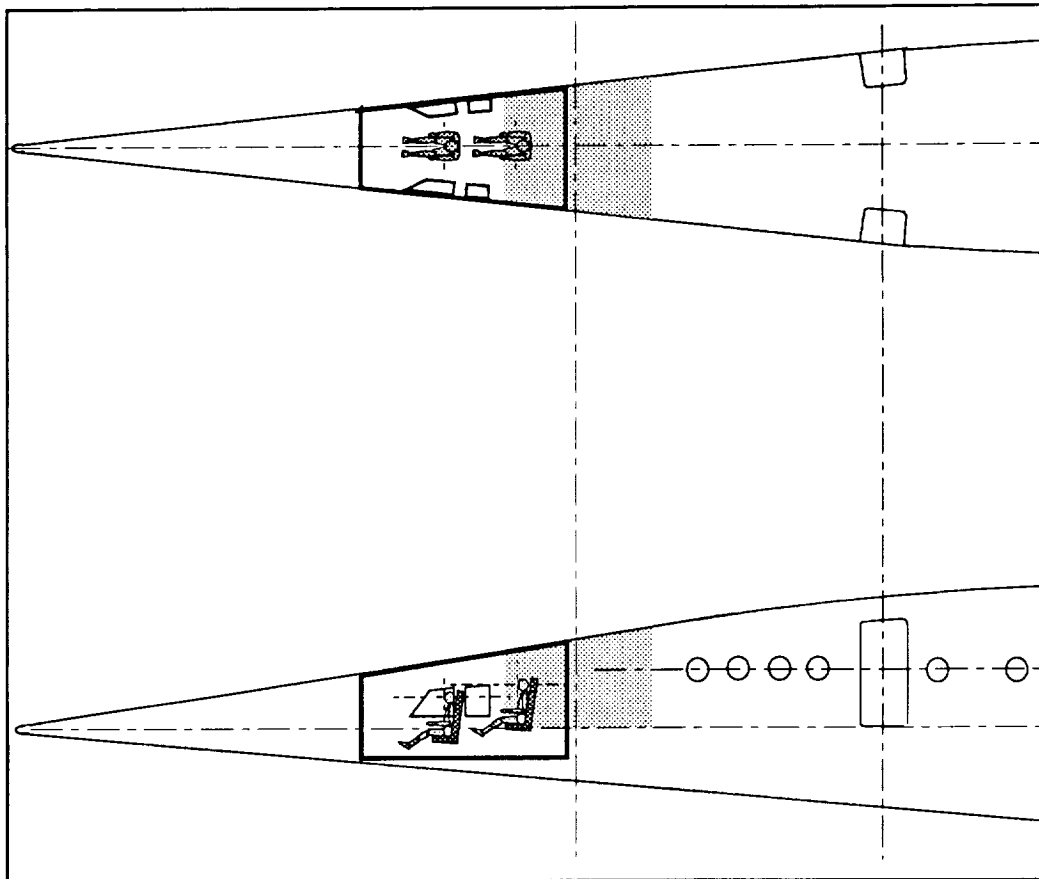


Figure 2. In-Line Tandem Seating

Offset Tandem Seating -

In order to position the crew compartment as far forward as possible, the forward crew position was offset from center line at a distance that would allow for the minimum lateral clearance that was established in the original side-by-side configuration. The rear crew member was repositioned to the right of centerline to a position that retained the minimum lateral distance from the cockpit wall. However, there was little space for ingress and egress of the forward seating location with the rear position compressed upon the forward position. This is apparent in Figure 3.

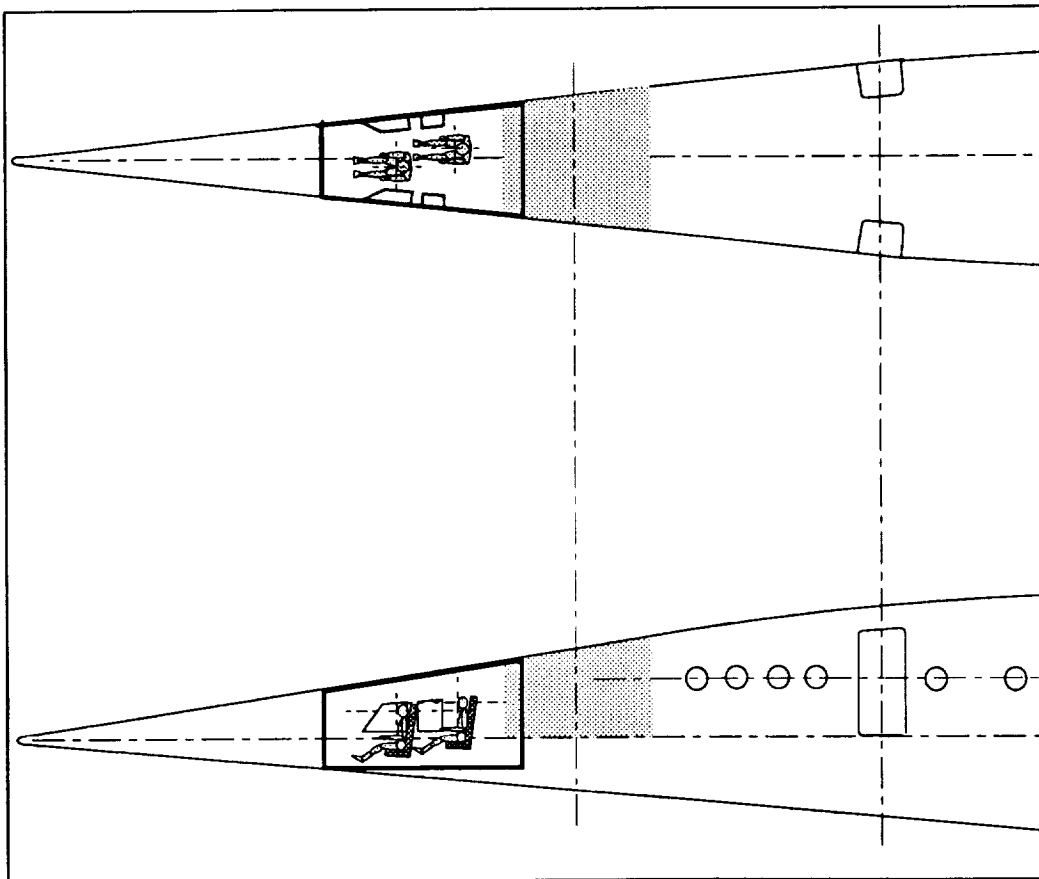


Figure 3. Offset Tandem Seating

Offset Extended Tandem Seating -

This configuration is much like the previous configuration with the exception that the rear crew position has been moved farther aft. A nominal distance from the rear of the crew compartment was established in order to allow space for cabin-installed electronics and/or a jump seat for a third crew position (observer). This configuration is shown in Figure 4.

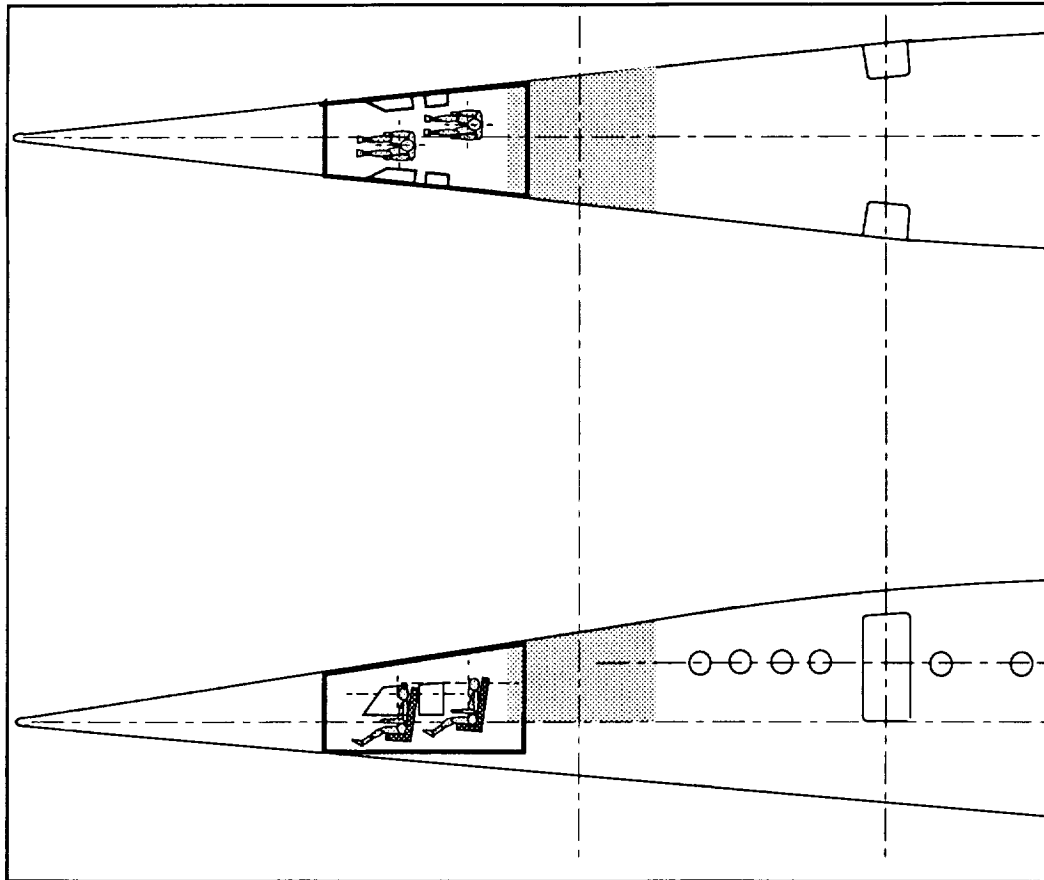


Figure 4. Offset Extended Tandem Seating

Offset Extended Tandem - Instrument Arrangement -

The offset extended tandem seating configuration (Figure 5) offered the most acceptable arrangement for both flight crew and total passenger accommodation. The relocation of the crew compartment to the farthest forward fuselage position opens up space for two additional rows of passenger seats. This could equate to as many as twelve (12) additional seats if they are added near the mid-body location. The advantages of this configuration are:

- o Adequate separation of both front and rear crew positions to allow for ease of ingress and egress.
- o Elevated rear crew position that permits "over-the-shoulder" viewing of the front crew position.
- o Identical instrument layouts. Movement from one seat to the other is easily accommodated.
- o Seat locations permit the use of large-screen displays for each crew position.

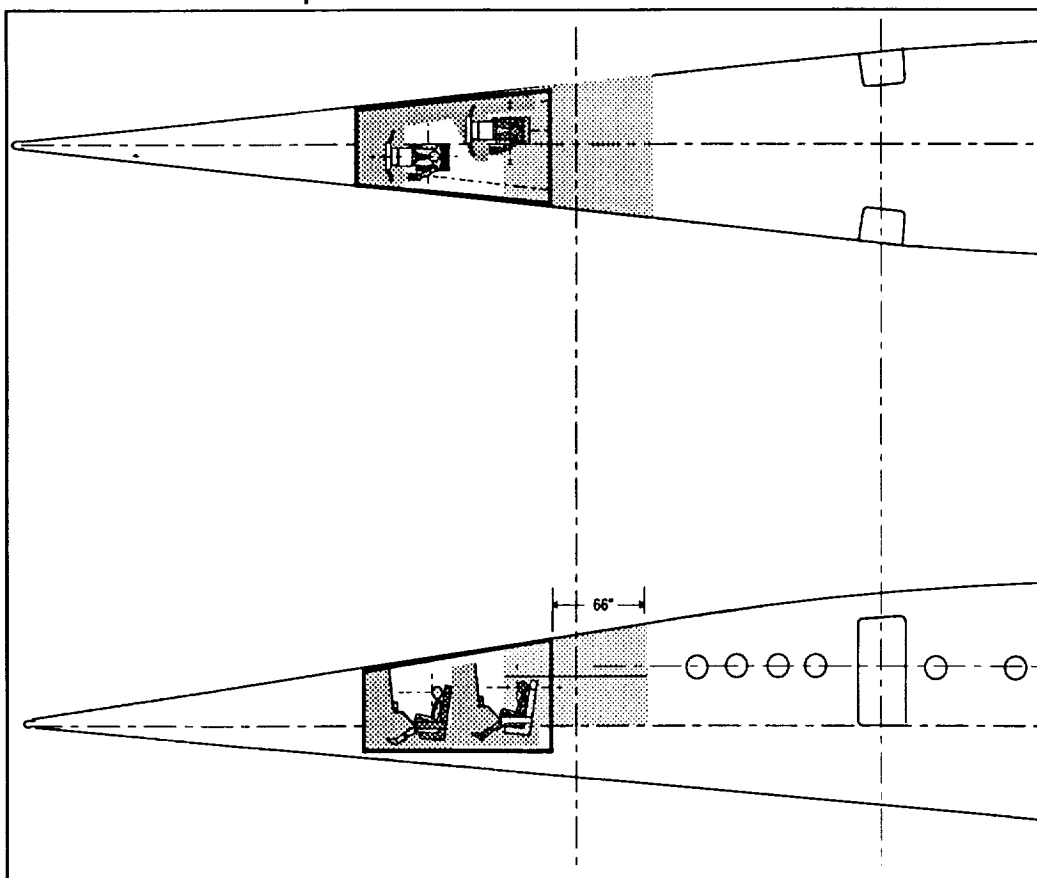


Figure 5. Offset Extended Tandem - Instrument Arrangement

Although the original side-by-side configuration was drawn with windows installed on the sides of the crew compartment, the refined version of the wrap-around instrumented crew station has no windows. The presence of the windows add little to the cockpit's functionality, but they could contribute to degraded cockpit conditions through light emissions that "wash out" the visual displays.

The most current version of the offset tandem seating configuration has evolved as a result of accomplishing the following:

- o Moving both the forward and rear crew positions aft
- o Reducing the length of the entire crew compartment by 1 foot in the forward area
- o Increasing the length of the aft crew compartment by 6 inches
- o Moving the entire crew compartment aft by 6 inches
- o Repositioning the crew positions laterally and vertically in order to use the available space most efficiently for installation of the vertically-mounted large-screen display.

Current Configuration -

This last iteration (Figure 6) was necessary due to the restrictions that were placed on the front crew position's foot/leg extension space. The cylindrical shape of the forward fuselage provides limited floor area when the crew compartment is placed at a farthest forward location. This restriction limits both lateral and forward placement of the forward crew position. The tapering of the forward fuselage to a near needle-nosed extension, places restrictions on the vertical positioning of both of the crew positions due to the high extension of the vertically-mounted large-screen display. Adjustments of both crew positions as well as the movement of the entire crew compartment aft was necessary to achieve the following:

- o Maximum separation of both crew positions, both laterally and longitudinally, in order to facilitate the ease of ingress/egress of both crew positions

- o Maximum vertical extension of the elevation of the aft crew position. The vertical extension contributes to the front crew position being visible from the aft position
- o Sufficient space for the foot positions/leg extension for the forward crew position

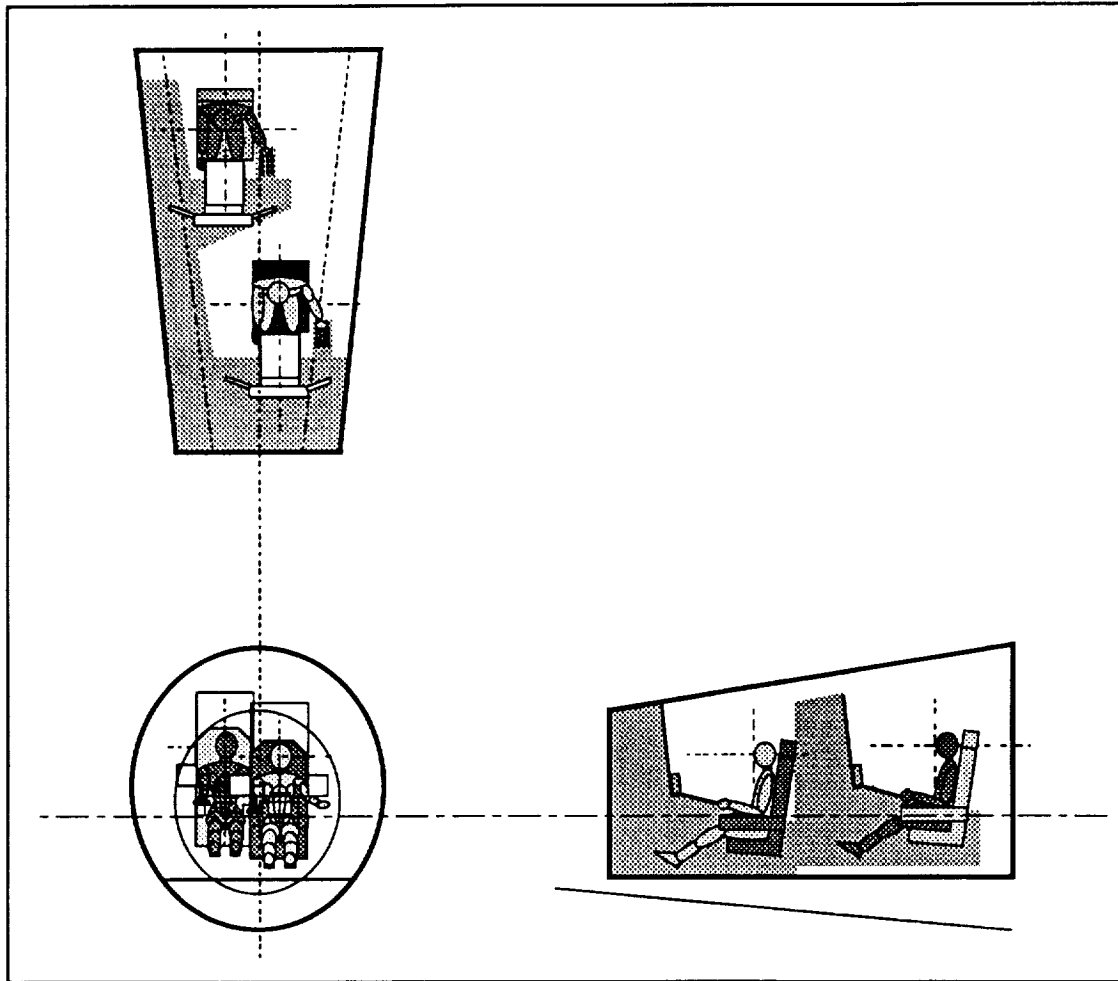


Figure 6. Current Configuration

APPENDIX D

HSCT Crew Station Configuration Studies

I. BACKGROUND -

The general arrangement drawings of the MODEL D-3235 - 2.4 -1 version of the High Speed Civil Transport shows a tandem seating arrangement with the front and rear crew positions located at stations 220 and 270, respectively. The tandem seating arrangement concept for the flight crew was driven originally by the requirement to investigate alternatives that would have an effect on aircraft costs. The original side-by-side crew seating arrangement did not take advantage of the useable space available in the forward fuselage area, therefore, an alternative to this original design was investigated (see High Speed Research Systems Studies Progress Report, 30 August, 1991, Enclosure 1). The tandem seating arrangement allowed for a relocation of the crew compartment to a position that was 66 inches forward of the original side-by-side location. The tandem seating design was an attempt to better utilize the available space to permit either: 1) a larger passenger accommodation (a possibility of two additional seat rows) or 2) a down-sizing of the airplane to reduce design, assembly, and operating costs. Due to design constraints that were not readily apparent in the initial configuration investigations, the drawings of the latest version of the HSCT show neither of these considerations. Crew station designers are currently re-evaluating the original side-by-side seating arrangement.

II. APPROACH -

The approach began with a review of the 2.4 - 1 drawings provided by the Advanced Commercial Programs Design Engineering group. It was apparent that the fuselage, in addition to the designated crew compartment area, had changed to accommodate aerodynamic considerations. The revised drawings were re-created and scaled as required to be used in the graphics development software.

A. Anthropometric Considerations -

A static human model was developed using anthropometry that was obtained from specifications that had applicability to this project. Anthropometric dimensions were included in the revised model as shown in Figure 1. The tandem seating arrangement model, with the revised anthropometry, was moved into position in the Model 2.4 1 drawing to assess the effects of the reshaped fuselage on the crew area (see Figure 2).

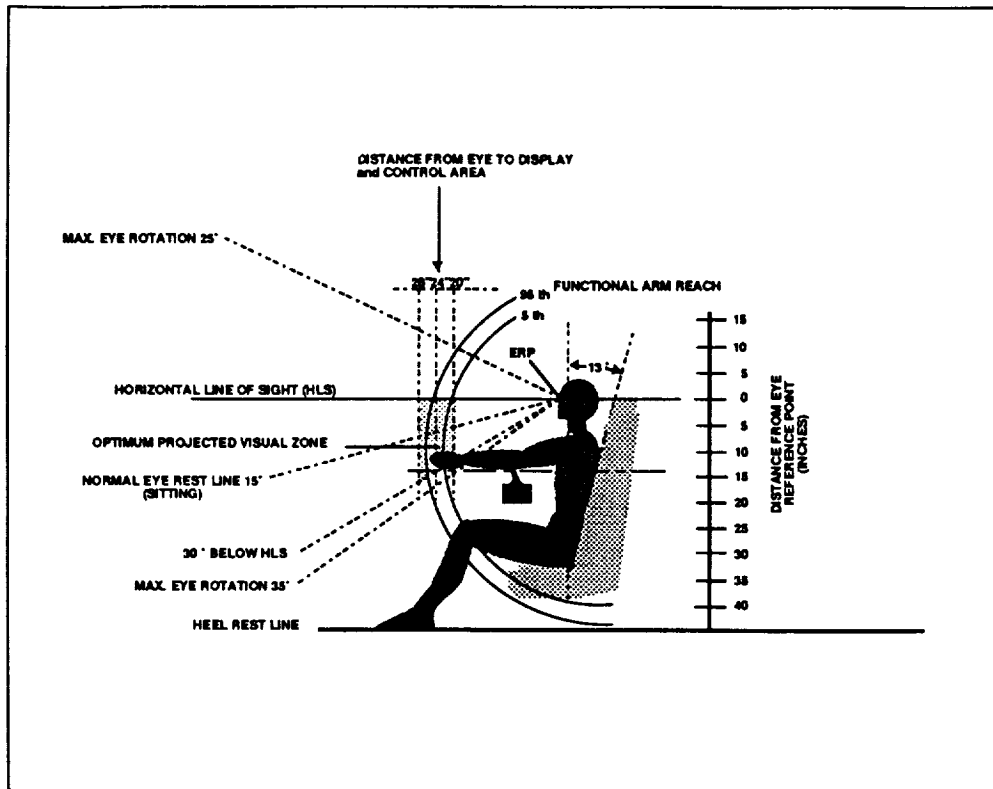


Figure 1. Anthropometry of Pilot Position

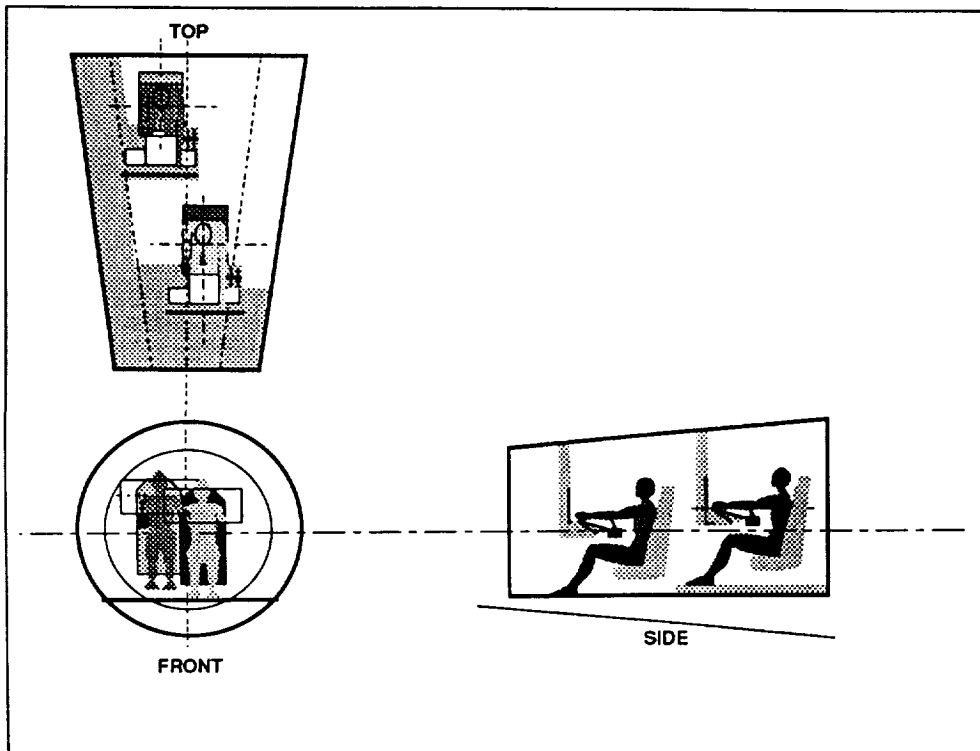


Figure 2. Tandem Seating Arrangement
(HISCT MODEL D-3235 - 2.4 - 1)

B. Horizontal Installation (Large-Screen Display) -

Tandem Seating Arrangement -

The synthetic vision installation used in this assessment was a horizontal arrangement of the 18" X 32" large-screen display. This was done in order to make an assessment of this type of installation and use it as an alternative to the vertically-mounted one used in the original tandem concept. The horizontally-mounted large-screen display does not cause any installation limitations provided the basic front/rear crew positions remain unchanged. The horizontal installation does provide for additional clearance above the knee area as shown in the comparisons of both installations in Figure 3. Currently NASA is using a 15" X 40" horizontally-mounted large-screen display centered in front of the viewer (pilot) at a nominal distance of 28" from the eye reference point (ERP). The NASA configuration was unable to be located satisfactorily in the area that is provided by the optimized offset tandem seating arrangement. In addition to the large-screen display, two additional (8" X 8") displays mounted at the lower edges of the large-screen display are included for use as system status and/or engine monitoring and control displays. A 12" X 12" map display is installed between the 8" displays. The map display functions as a moving-map indicator during both ground and in-flight operations. Fly-by-wire and engine throttle controls are mounted right and left of the pilot respectively in identical positions at each pilot station.

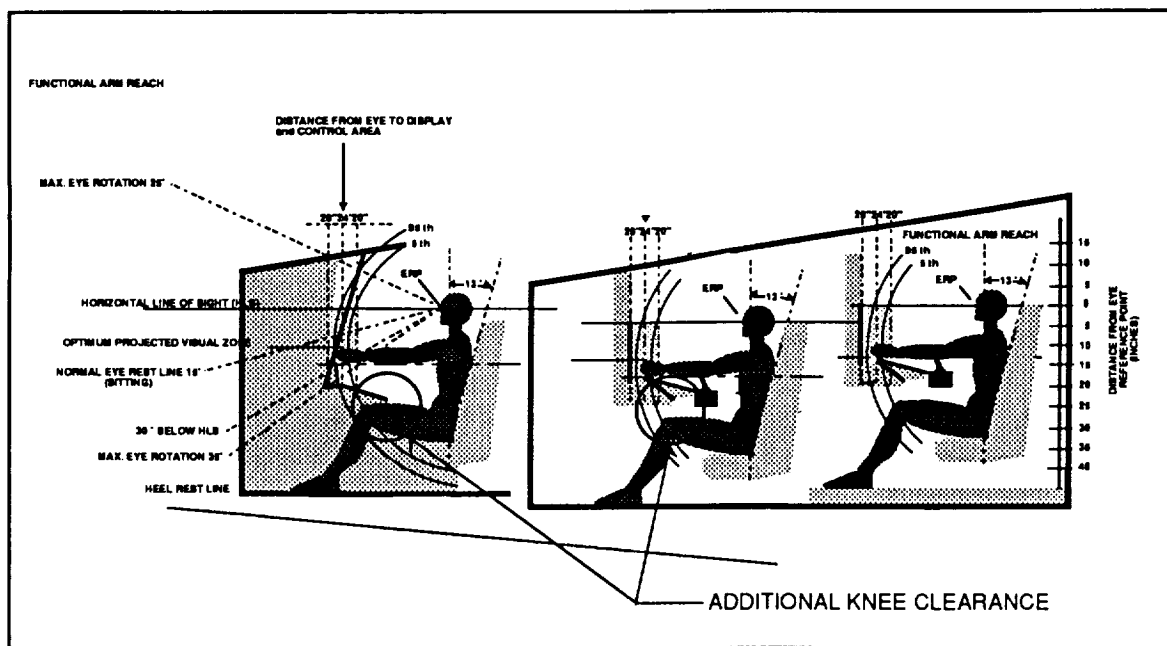


Figure 3. Installation Comparisons

Side-By-Side Seating Arrangement -

There is little to be gained by going to the tandem seating arrangement if it has little economic impact. Although the tandem arrangement exhibits a unique and non-traditional crew configuration in a commercial cockpit, it also has the potential to present crew coordination and operations difficulties, without an in-depth analysis of the crew operating environment.

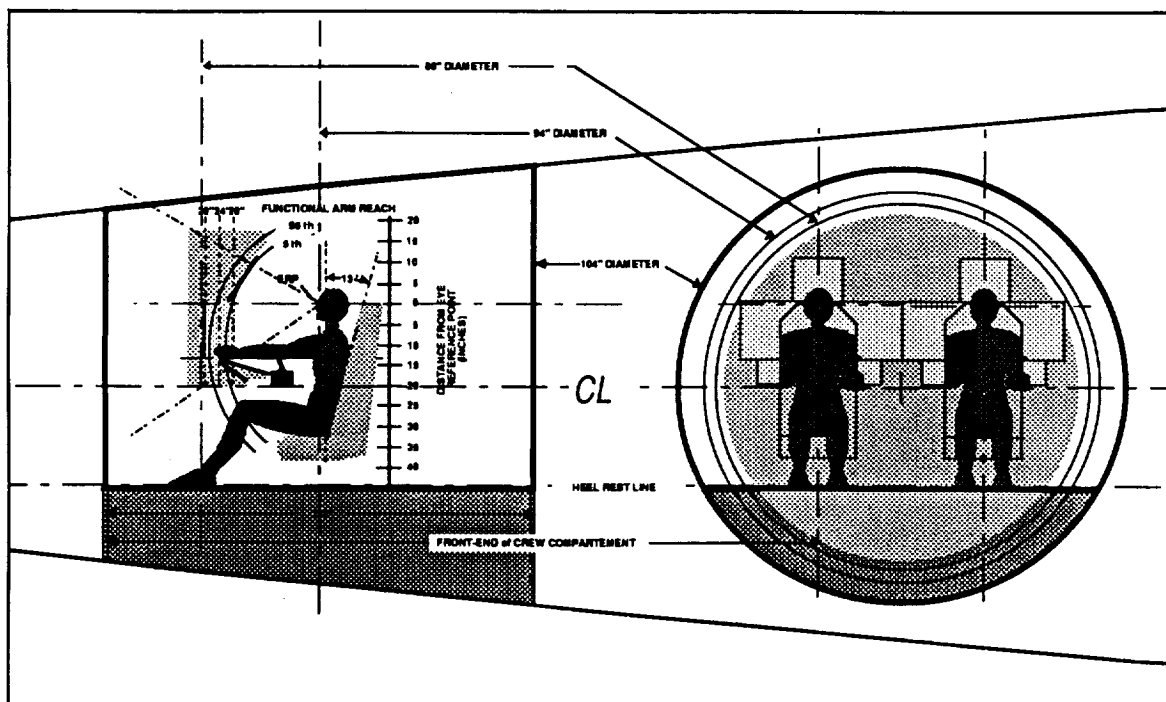
The reassessment of the side-by-side seating arrangement began by the relocation of the crew compartment with the ERP at Station 295. This location allows for a 94" diameter space at the intersection of the ERP along the forward fuselage radius centerline. The crew compartment has a large diameter of 104" at the aft location, and a small diameter of 88" at the forward end. The overall length of the crew compartment is 103" (approximately 8.5 feet). The heel rest line (HRL) lies precisely along the floor of the crew compartment and its location intersects the cylindrical shape of the forward fuselage approximately 25" below the fuselage centerline, giving sufficient floor area for leg extension and movement of any foot controls.

For the side-by-side installation, the basic instrument display grouping has remained the same as that in the tandem seating configuration, with the addition of a 12" X 12" display installed above each pilot position. These are located within the pilots' reach/touch zones. These touch-sensitive displays will permit overhead control switches and indicators to be activated and operated in this area.

15" X 40" Display -

The horizontal large-screen display in the side-by-side arrangement may be a 15" X 40" configuration similar to the one currently being used by NASA. This installation would require no other considerations than the movement of the crew positions laterally to a point that centers each position on the 40" display. This is necessary to be able to achieve the stereoscopic effect of the flight guidance elements presented on each individual display. The possible side effects of this type of arrangement is the reduction of the distance between each seat. Minor difficulties in ingress and egress may be experienced because of the reduced width of the between seats aisle.

Approximately 70° field-of-view (FOV) is available using the 15" X 40" horizontally-mounted display. It is presumed that the entire viewing area may not be required for all phases of flight. If the FOV is reduced at any time, the area on the display that is not being used for primary flight instruments may be "windowed" as necessary to permit it being used for additional systems status or similar type displays. A two-view (side and rear) drawing of the 15" X 40" large-screen display installation is shown in Figure 4. Note that adequate clearance is provided above each crew position and that the installation of the 15" X 40" display can be accommodated at the 94" diameter location. The overhead 12" panel is positioned well within the outer reach area of the 5th percentile male. This area will be modified as required to accommodate female anthropometry when that requirement surfaces.

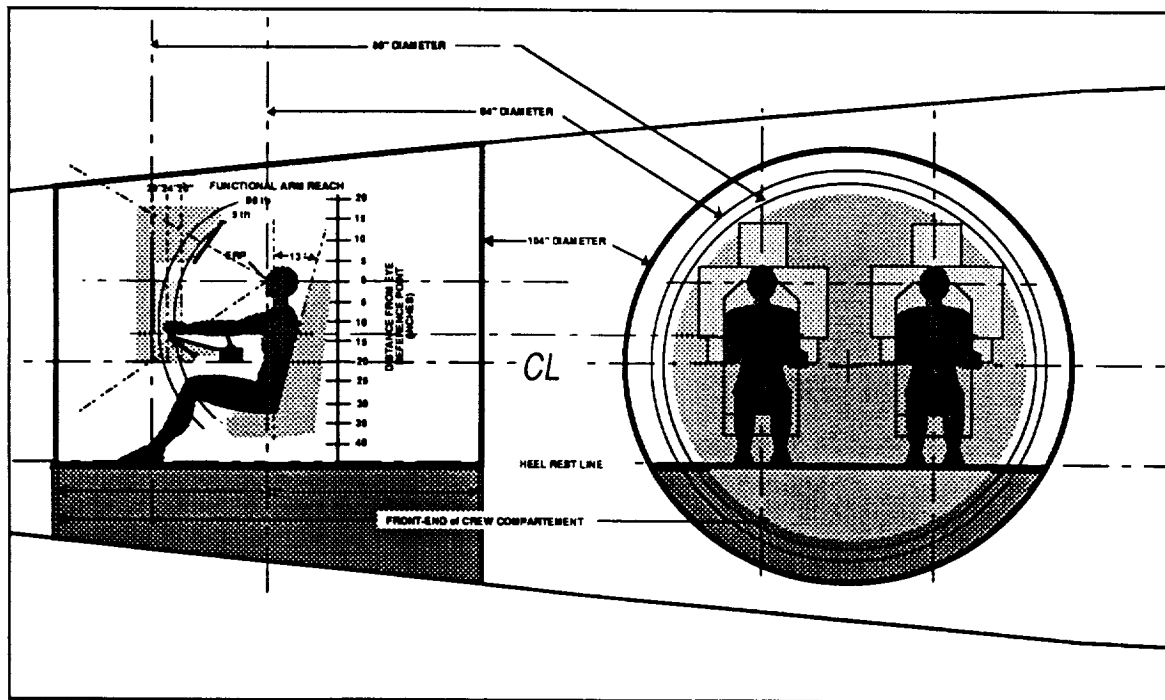


**Figure 4. HSCT Crew Station Configuration
(15" X 40" Display)**

18" X 32" Display -

A display of this size was used in the tandem seating arrangement. It was installed vertically to permit a specific display configuration for the unique tandem seating. The vertical mounting provided an unrestricted viewing area from the rear to the front seat. Viewing of the rear seat from the front could have been accomplished through the use of a simple mirror placed at the proper location.

The installation of the 18" X 32" large-screen display is very similar to that of the 15" X 40" display. It fits comfortably in the crew compartment at the 94" diameter and its reduced width allows for greater distance between the two seats (42" from ERP). The overhead 12" panel is well inside of the outer reach limits of the 5th percentile male. It is estimated that the width of this installation will provide a FOV of approximately 55°. An illustration of the 18" X 32" display installation is shown in Figure 5.



**Figure 5. HSCT Crew Station Configuration
(18" X 32" Display)**

III. SUMMARY -

The current side-by-side crew station configuration is shown in Figure 6. This figure illustrates the side-by-side seating arrangement with the design eye reference point (DERP) positioned 44" above the heel rest line (HRL). This position is used as the eye reference point (ERP) and it establishes the base position from which all other dimensions within the cockpit are referenced. Unlike the commercial aircraft design approach that has been acceptable in the past, the ERP becomes a position that is driven primarily by internal constraints in the cockpit area and not by the external viewing area, as it would be in an aircraft having a front window screen for external visibility.

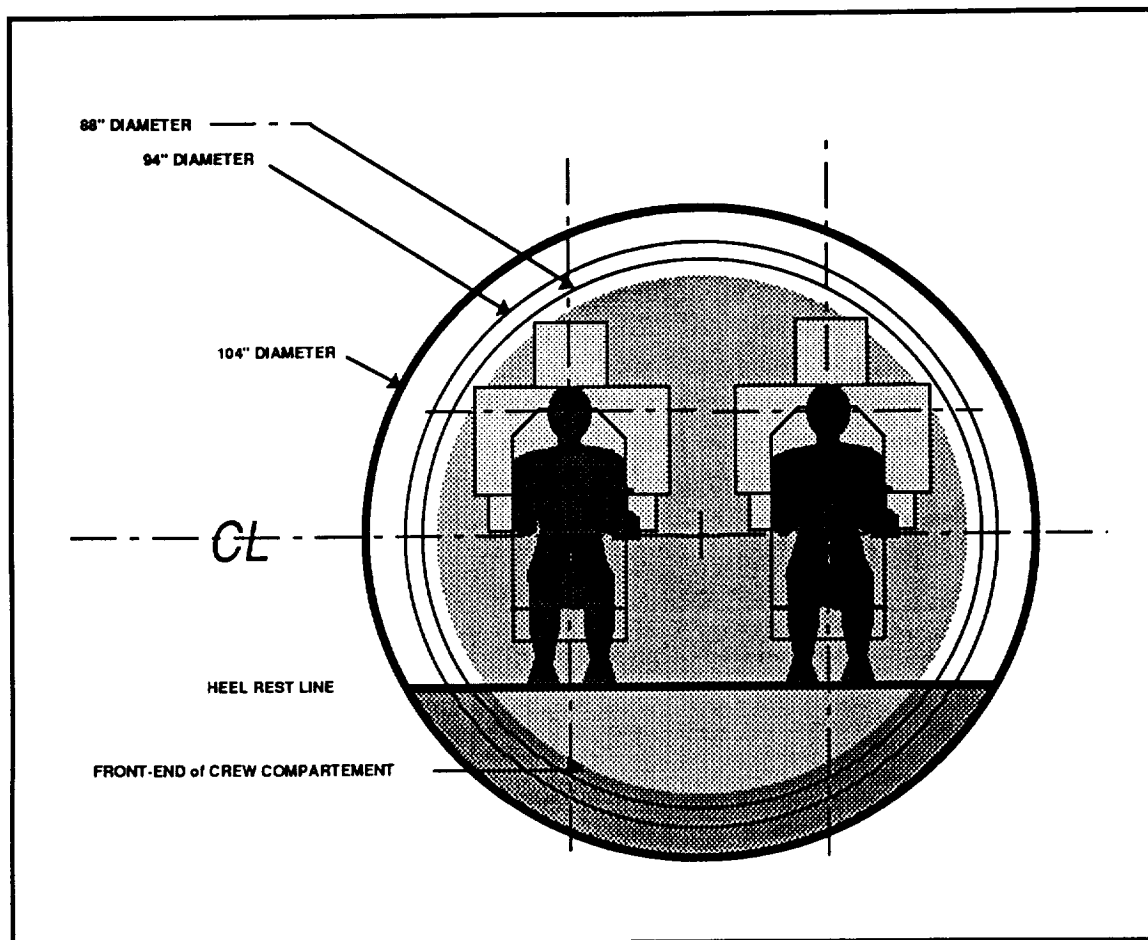


Figure 6. Current Side-By-Side Crew Station Configuration

The pilot manikin was placed in a restrained, seated position at a standard 13° seat back angle with both feet resting on the heel rest line. This position

places the manikin in the Zone 2 reach envelope where there is no shoulder harness and an upright position is maintained. This position defines the limits of flight deck for controls and/or surfaces that must be reached by both pilots. The area forward of the foot position provides adequate space for foot controls (rudder pedals) that can be adjusted for forward/aft movement of approximately 8.25 inches. The seat position may be adjusted vertically a maximum of 5 inches and horizontally (forward/aft) 3 inches. Provisions for lateral adjustment of the seat is available to allow for ingress and egress. Primary vision areas have been identified with upper and lower vision angles based around the maximum eye rotation angles of 25° and 35°, respectively. The vision area plots provide areas for placement of displays and, in effect, fix the distances for controls associated with the displays. The entire crew station area may have limited three-dimensional controls or switches other than the fly-by-wire flight control sidesticks and the throttle quadrant. The majority of the controls will be embedded in the displays as touch sensitive areas designated as active switches, buttons, and/or knobs [see IV.C(6) of Design Guidelines for Electronic Controls/Display Systems (HSCT Configuration)].

The external vision requirements specified in AS580B (SAE), may not be applicable to the HSCT considering the absence of external forward visibility. The external vision requirements have been used in the past to define the configuration of the windscreen. It may be used in the HSCT to determine the minimum viewing angles for a synthetic vision display, assuming that the display will be such that its perspective has a one-to-one conformation to the outside world. Some other ratio may be more conducive to the HSCT since there will be no external viewing to conflict with the images produced on the synthetic vision displays.

Both the tandem and side-by-side crew station configurations will continue to be investigated until a definitively superior concept emerges and/or other design constraints force a selection.

APPENDIX E

HSCT Cockpit Displays

Baseline Visual Displays -

- A centrally mounted, large-screen, wide-angle vertical situation display (VSD) heads-up display (32"V X 18"H) upon which both stroke and raster can be projected from electro-optic (EO), infrared (IR) and/or milli-meter (RADAR) sensors, for generation of a forward-looking image of the landing area, including runways, taxiways, and immediate surroundings, in proper three-dimensional (3D) perspective with ILS/MLS navigational guidance symbology overlaid. The displays are arranged in the cockpit area as shown in Figure 1.

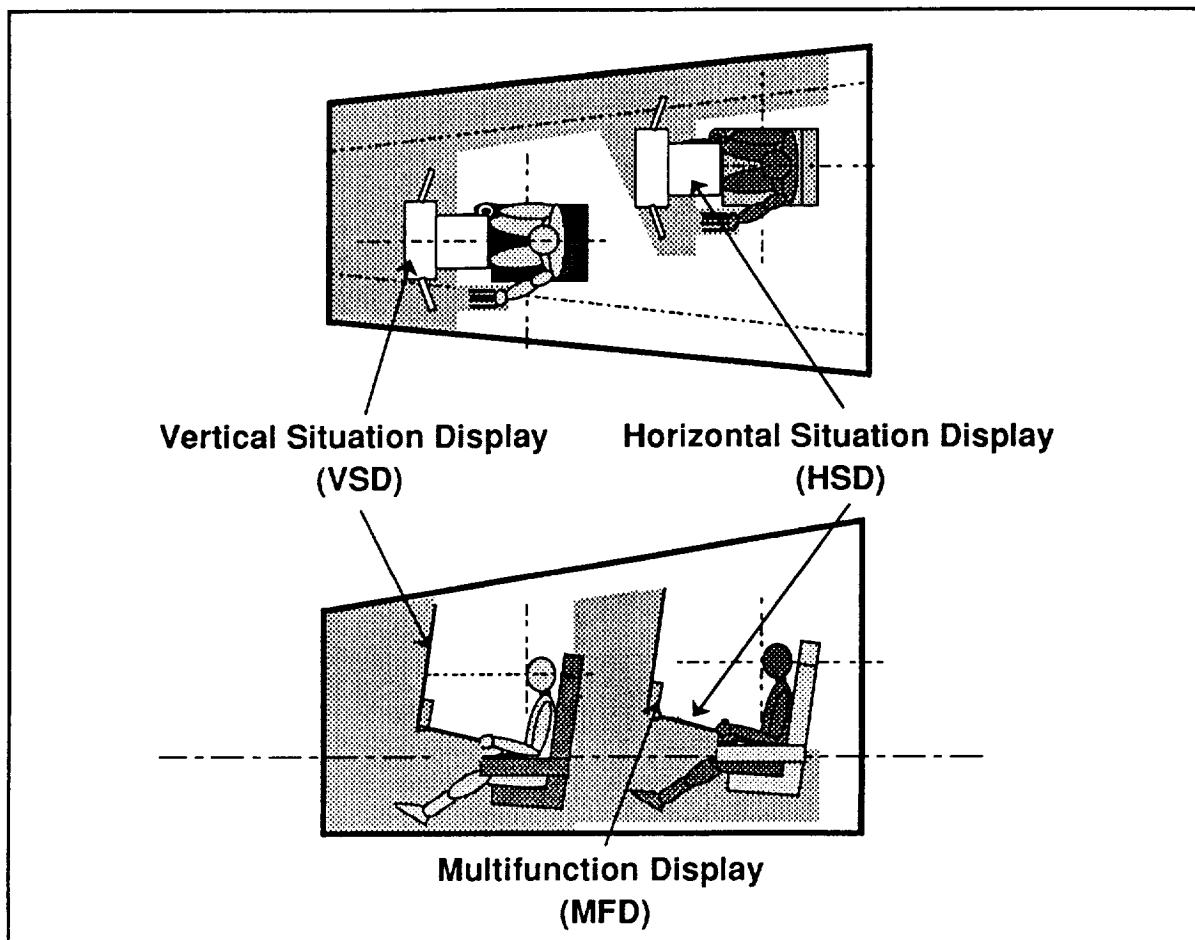


Figure 1. HSCT Cockpit Layout

- A smaller (12" X 12") flat-panel screen, mounted on an angle below the VSD, to serve as a God's eye-view horizontal situation display (HSD) of a moving map, navigational display with a track-up orientation which can be slewed in synchronization with platform position to maintain alignment during curved, multi-segmented approaches. It will display navigational data from standard approach/departure charts (e.g., airports, NAVAIDS, waypoints, intersections, etc.) on an automatic/selectable basis with zoom capabilities as well as a lower window for vertical profiles.
- Adjacent to the VSD, in a partial wrap-around arrangement, there are two (2) 8" X 8" flat-panel displays, with touch screen overlays. These multi-functional displays can serve as either system status displays or as various performance monitor displays, at the discretion of the flight crew. They may also serve as Electronic Library System (ELS)/Onboard Maintenance System (OMS) displays, Data Link (DL) terminals or airborne display surfaces for presentation of a wide variety of weather data. The display functions will be selected from a hierarchical menu scheme with flexibility in forward/backward paging and/or specific associative look-ups. A three-view illustration of the display configuration is shown in Figure 2.

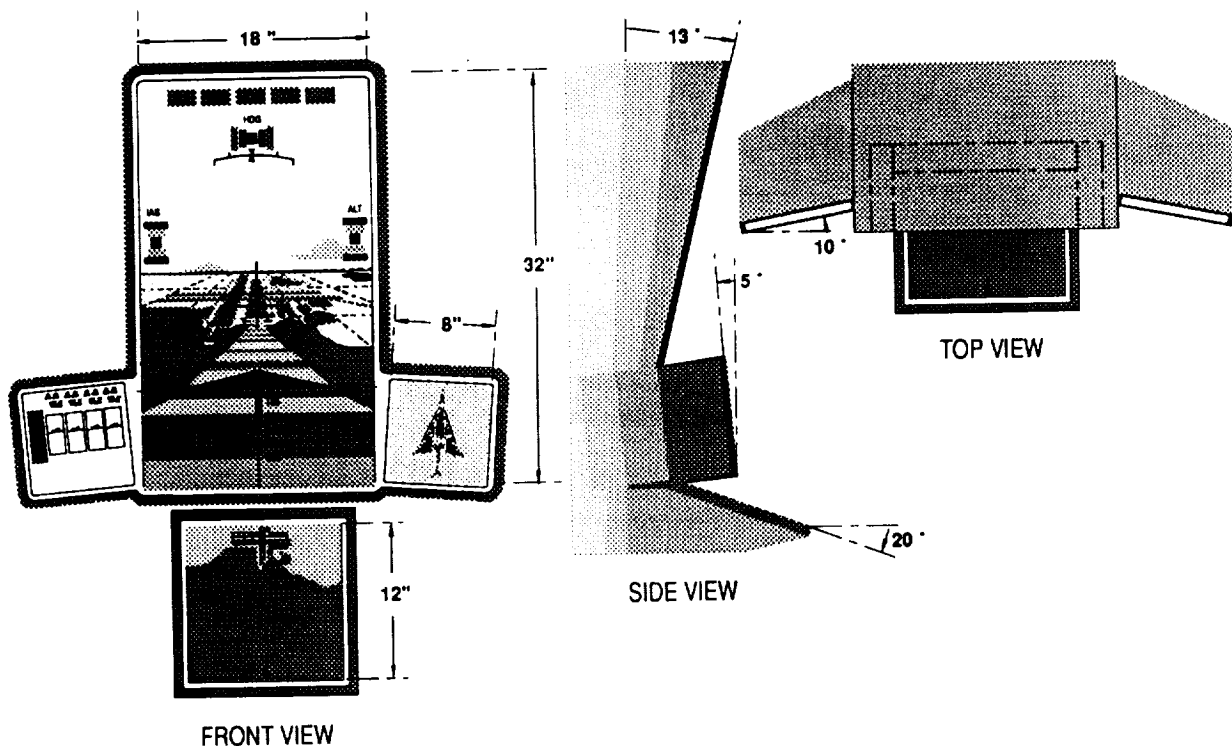


Figure 2. HSCT Display Configuration

Potential Display Formatting -

- Except for takeoff and landing, the large-screen display will project a large 6" attitude display indicator (ADI) foveally located, with an *inside-out* frame references but utilizing a frequency separation principle and algorithms to provide *outside-in* for rapid changes, where vehicle symbol moves relative to a fixed horizon to provide compatibility with track-up navigational displays. The new attitude reference display will integrate position, vector and energy status information. Position is displayed as lateral and vertical angular displacements from desired flight path; vector as direction of flight both laterally and vertically which provides first indication of flight path disturbance in response to pitch/roll rates; and energy status or management symbology in which chevrons move up and down relative to wingtips of velocity vector and show potential flight path or *flight path angle* reflecting more than conventional airspeed, such as aspects of ground speed, including effects of wind.
- Adjacent to the ADI will be command display indicators of various flight path control parameters or error signals. These commands do not represent the true zero error flight path, but rather a signal, which used a basis for control, will produce successful guidance along the computed flight path. Hence, bank angle is utilized as a first derivative of heading. Such command displays will also provide predictive projections of a three-dimensional *path-in-the-sky* emanating from the ADI showing future track of the aircraft or a flight path preview (see Figure 2).
- The flight path itself will consist of a three-dimensional perspective ribbon projected in front of the air vehicle referred to as the "highway-in-the-sky". This display presents a *predicted* path indicating both lateral and vertical changes in the future trajectory. Additional cueing is provided for velocity and acceleration along the flight path as well as height above or below the nominal path.
- An assortment of display formats will be available to the flight crew during the various phases of flight or mission segments. The appropriate display(s) will be provided dependent upon the mission phase/segment and/or air vehicle configuration. HSD display scale will vary as the display requirements of the mission changes or it may be selected as needed, independently by either crew position at his/her station. During the after takeoff/climb-out phase of the mission, and during high-altitude cruise, the lower area of the large-screen vertical display is available to be used as additional 8" "windowed" display areas. Examples of typical displays are shown in Figure 3.

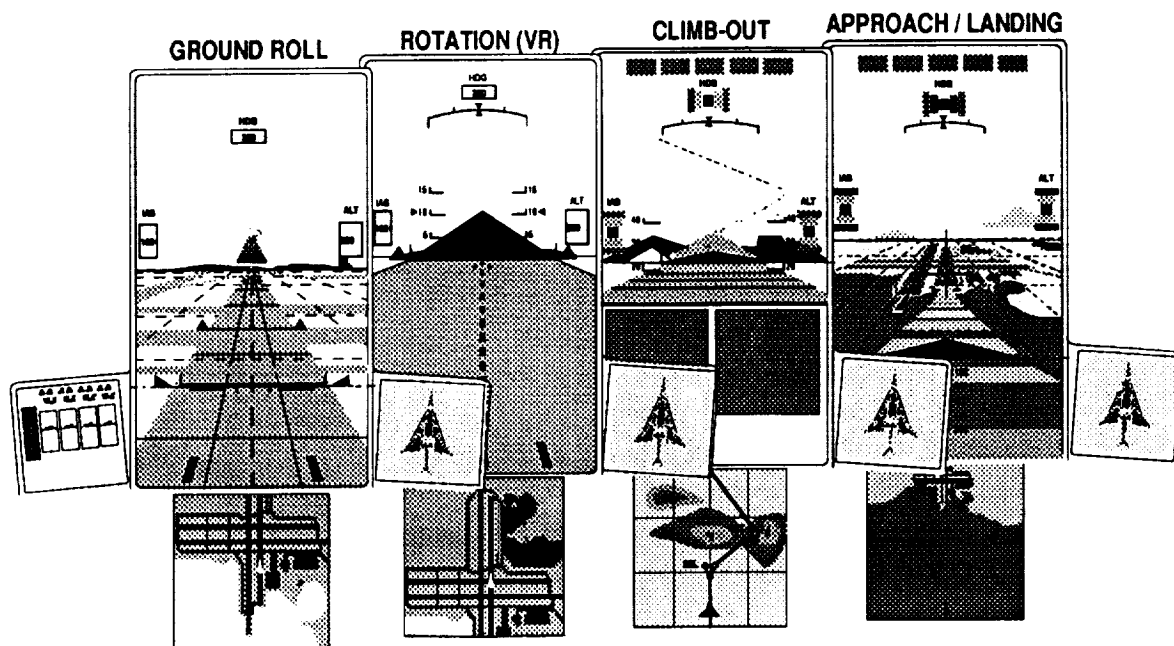


Figure 3. HSCT Display Formats

Additional Cockpit Displays -

Peripheral vision devices will be provided as rate-field and attitude reference displays to compensate for complete lack of external visibility. A *para-visual director* (PVD) will augment the perception of forward movement and the *peripheral vision horizontal display* (PVHD) attitude (pitch/roll) without reliance on foveal vision. The PVD is typically an electromechanical, servo-driven rotating barber pole mounted on either side of the cockpit while the PVHD is a narrow line (laser or light) projected projected across the cockpit instrument panel; both driven from the INS-computed velocity and attitude references.

APPENDIX F
DESIGN GUIDELINES FOR
ELECTRONIC CONTROL/DISPLAY SYSTEMS
(High-Speed Civil Transport (HSCT) Configuration)

I. PURPOSE - This document has data that has been extracted from Advisory Material Joint (AMJ) publication 25-11 and it provides guidance for the design and certification of electronic display systems that are used for guidance, control, and decision making by the pilots of commercial transport airplanes. This document is provided for use as advisory material only and it outlines selected areas of compliance to established rules governing cockpit displays. The High-Speed Civil Transport (HSCT) has unique requirements for pilot cockpit displays over and above the transports of the current generation, therefore, many of the "conventional" displays may be altered significantly in order to meet these requirements. However, many of the conventions that have been established in prior cockpits will be retained because they still have applicability to the HSCT.

II. SCOPE - The contents of this document cover the following areas:

- General Certification Considerations
- Information Separation
- Display Visual Characteristics
- Information Display
- Switching and Annunciation
- Map Mode Considerations
- Systems Status Displays

III. GENERAL CERTIFICATION CONSIDERATIONS

A. Display Function Criticality

With the arrival of electronic displays, the flight deck designer has a greater opportunity to integrate and display information from a variety of systems than he did with previously used flight deck components. This has allowed for more simplicity in aircraft operation through automated navigation, thrust, and control functions and their related display systems. Although normal operation of the aircraft has become easier, it is a more complex problem to determine the criticality of display functions, their information requirements, and the effects of failures on these more complex display processes.

B. Compliance Considerations

Human Factors

Humans are adaptable creatures which adapt at varying rates with varying degrees of effectiveness. The displays must be designed to be effective when they are used by pilots covering a wide spectrum of experience because what some pilots find as acceptable display formats may be rejected by another group of pilots. The human factors areas of interest should include evaluations or assessments that substantiates:

- Acceptable interpretation error rates that are equivalent to or less than the electromechanical instruments;
- Proper integration with other equipment that incorporates an electronic display feature;
- Compatibility with other displays and controls;
- Acceptability of failure modes;
- Usability of the displays in an operational environment; and
- Impact on training, both in terms of time to train and magnitude/complexity of training

IV. INFORMATION SEPARATION

A. Color Standardization

(1) The following relates functional meanings of displays to their acceptable display colors:

a) Display features should be color coded as follows:

Warnings	RED
Flight Envelope/System Limits	RED
Cautions, Abnormal Sources	AMBER/YELLOW
Earth	TAN/BROWN
Scales and Associated Features	WHITE
Engaged Modes	GREEN
Sky	CYAN/BLUE
ILS Deviation Pointer	MAGENTA
Flight Director Bar	MAGENTA/GREEN

b) Specified display features should be allocated colors from one the following sets:

	SET 1	SET 2
Fixed Reference Symbols	WHITE	YELLOW *
Current Data, Values	WHITE	GREEN
Armed Modes	WHITE	CYAN
Selected Data, Values	GREEN	CYAN
Selected Heading	MAGENTA **	GREEN
Active Route/Flight Plan	MAGENTA	WHITE

* The extensive use of the color *yellow* for other than *caution/abnormal* information is not recommended

** This is to be associated with analog parameters that indicate information such as *fly to* or *keep centered* type information

c) Precipitation and turbulence areas should be coded as follows:

Precipitation	0 - 1 mm/hr	BLACK
	1 - 4 mm/hr	GREEN
	4 - 12 mm/hr	AMBER/YELLOW
	12 - 50 mm/hr	RED
	50 > mm/hr	MAGENTA
Turbulence		WHITE or MAGENTA

d) Background color ***GRAY or other shade***

Background color is recommended to enhance the display presentation

(2) When there is a necessity to deviate from the recommended color assignments, the designer should ensure that the color scheme does not promote confusion when the display is used.

(3) Colors should be selected on the basis of their *chrominance separation*. Regions of relatively high color confusion exist between the following:

RED	<--->	MAGENTA
MAGENTA	<--->	PURPLE
CYAN	<--->	GREEN
YELLOW	<--->	ORANGE (Amber)

Any requirement for the pilot to discriminate between shades of the same color for symbol meaning in the *same* display should be eliminated. Display color selections must ensure that the presence of color enhances the separation of logical display *functions* and display *data*. If the cockpit has numerous displays, the color selection scheme must be consistent throughout the cockpit.

B. Display Interpretation and Workload

(1) Color selection will have an effect on display interpretation workload. The task being performed in addition to the operation of the crew should be related to the color selection so that display item recognition and selection decreases the likelihood of errors. This is particularly important in situations where *response rate* demands are exceeding *response accuracy* demands. Colors should be limited to as few colors as practical to present the information. Color groupings should follow a designed and logical scheme. Haphazard groupings of colors and the use of too many colors may cause the pilot to perceive the display as "cluttered" and dangerously extend the time of symbol interpretation.

(2) The *shape* of a symbol, as well as color and contrast, provides an added dimension to the pilot's ability to discriminate information. The ability to sharply focus on red objects, or discriminate between blue or green is reduced as age increases. For the general pilot population, display symbology should be identified by more than one distinctive coding parameter (e.g., color, shape, size, location, etc.)

C. Symbology Standardization

SAE Aerospace Recommended Practice (ARP) 4102/7 provides guidance on Electronic Attitude Director Indicators (EADI) and Primary Flight Displays (PFD) used in the flight deck of commercial transport aircraft. This document provide names, recommended symbol, and acceptable alternatives for each of the symbols used on either the EADI or PFD. ARP 4102/7 states that "Recommended symbols should be used wherever possible, however, symbols may be refined as a result of dynamic testing or developed to display new functions." The HSCT will be operated by transport pilots familiar with standard symbology. Many elements of the display formats that lend themselves to standardization of symbology should be retained. This could shorten the training and transition times when the pilots change to this specific aircraft

type. Also, the retention of standard symbology could hasten the acceptance and certification of the cockpit instrumentation suite.

D. Symbol Positioning

(1) Pilots develop habits of looking for specific information in selected areas within a display. Interpretation errors or interpretation response times may increase if there are inconsistencies in the location of different types of messages or information. Here are some recommendations for position consistency for various symbols and parameters:

- Autopilot and Flight Director operating modes
- All warning, caution, and advisory annunciations
- All sensor data: Altitude, airspeed, heading, glideslope, etc.
- All sensor failure indications (flags). Sensor failure indications should appear in the area where the sensor information is normally viewed
- Either the pointer or scale for analog values should be fixed. Moving pointers and scales tend to give the illusion that the indicator is "breaking up"

(2) Normal and abnormal indications should be located so that there is immediate differentiation. Abnormal indications should not be displayed in positions that are normally used by normal indications. Also, abnormal/normal indications should be displayed using different shapes, sizes, or colors.

(3) The Captain and First Officer may have different displays available during specific phases of the flight. Whenever there is a requirement for differing displays, the designer should ensure that there is no potential for misinterpretation when display information is compared.

E. Display Clutter

A cluttered display is one that is characterized by the following:

- An excessive number of symbols
- An excessive variety of symbols
- An excessive number of colors
- Small spatial relationships of the symbology

A cluttered display contributes to increased time to process information and leads to misinterpretation. Conveying information in the simplest fashion will be one of the primary goals of the HSCT display format design. The outcome of this should be a reduction in display interpretation time and reduced misinterpretation of the displayed information. Another goal of display format design in the HSCT will be to provide the pilot the essential information required to perform the task at hand. This will serve to limit the amount of information available to only that that is needed at a given time. Tasks usually become more difficult as the amount of information increases and what may be considered as *primary* information is blended in with *secondary* information to cause the pilot to be distracted by the "information overload" condition. Pilot selection of information is desirable since this option allows the pilot to "individualize" his presentation. At times, especially during an emergency condition, it would be desirable to design the system to automatically "unclutter" a display and provide the pilot the minimum essential information needed to cope with the emergency condition.

F. Two-Dimensional Displays

The three-dimensional aspects of commonly-used electromechanical attitude indicators play an important role in instrument interpretation. Pointers, symbols, and bars overlay each other on a moving background to give the pilot a simple "quick-glance" interpretation of the attitude of the aircraft. The designer of the two-dimensional HSCT display will attempt to provide the same level of conspicuousness of each display element by using a combination of shapes, sizes, and colors to define the distinctive characteristics of each element of the display.

G. Attention Getting Displays

Attention-getters are used to alert the pilot to important changes in aircraft control modes, critical attitude limits, excessive angle-of-attack, etc. An effective attention-getter must ensure that some noticeable change becomes evident to the pilot. Legend changes alone may be inadequate to display automatic or uncommanded mode changes, therefore, changing colors, shapes, and/or short-term flashing symbols are effective attention-getters. In addition, motion is also effective if integrated properly into the entire display. Permanent or long-term flashing symbols should not be used.

V. VISUAL CHARACTERISTICS

A. Visual Display Characteristics

SAE Documents AS 8034 and ARP1874 provide direction for the visual display characteristics of electronic displays.

B. Colors and Luminance

(1) Environmental and lighting conditions should have the least effect on the readability of displays. There are four significant lighting conditions that should be considered during the development and testing of electronic displays, they are:

- (a) Direct sunlight entering the cockpit through a side window

- (b) Sunlight entering through a front window reflecting off of light colors in the cockpit
- (c) Night and/or dark environment.
- (d) Sun appearing above the forward horizon and above a cloud deck in the pilot's eyes. This is usually a prolonged situation and probably the most critical of the four conditions

The requirements of the HSCT design may eliminate all of the above conditions since the flight deck area may not have any windows that would permit sunlight to enter the cockpit. Lighting levels in the cockpit would be controlled by the crew and display luminance interference would not be a consideration.

(2) Display system lifetime may be increased through the use of automatic brightness adjustment systems. Reduced levels of brightness may be acceptable during the phases of flight where the HSCT is being flown automatically and the display is being used by the pilot only to monitor and/or backup automation.

C. Visual Display Characteristics

The refresh rate of a display is a major determinant of the undesired temporary variation in display luminance of a symbol or group of symbols. If the data content of the screen is increased, the refresh rate may be reduced and the rate of flicker increased. Refresh rates above 55hz for stroke symbology or non-interlaced raster and 30/60hz for interlaced raster are considered to be generally satisfactory for minimum flicker in a display.

D. Dynamics

Jitter, jerkiness, or "ratcheting" appearance of highly dynamic analog symbols used in direct airplane control tasks are distracting and objectionable to pilots. Screen data update rates should be adequate to eliminate any "step" motion in the concerned symbols. Minimum update rates equal to or greater than 15hz has been determined as acceptable for attitude displays, while 7.5hz or greater has been determined to be acceptable for engine parameter displays. In any case, any lag present in the display system should be consistent with the aircraft control task associated with the display.

VI. INFORMATION DISPLAY

Display elements and symbology used in real-time control should be intuitive and "natural", and not dependent on extensive training or adaptation for correct interpretation and utilization.

A. Basic Relationships

The established "T" relationships of instrumentation arrangement specified in the Joint Airworthiness Regulation (JAR) Part 25.1321 should be retained as much as practicable in the HSCT. Deviations from the JAR cannot be granted without substantiation based on the applicable human factors research.

(1) Deviations from the basic "T" arrangement are permitted as described below:

- (a) Airspeed and altitude instruments that are external to the attitude display may be lowered up to 15 degrees from the center of the fixed airplane attitude reference, or raised up to 10 degrees.
- (b) A vertical scale type radio/radar altimeter indication may be shown between the attitude and altitude displays.
- (c) A display of vertical velocity may be shown between the attitude and altitude displays

(2) Airspeed and altitude within the electronic display should be arranged so that the current value of the parameter being displayed is located as close as practicable to the horizontal line extending from the center of the attitude indicator. Aircraft heading should be displayed at a position that is vertical and below the center of the attitude indicator (this does not preclude an additional display of heading being shown at a position that is horizontal to the attitude indicator.

- (a) Airspeed and altitude displays that have moving scales should have their current values aligned with the center of the fixed airplane reference
- (b) Critical airspeeds for takeoff, cruise, and landing should have an indication where the current value is within 15 degrees of the horizontal line from the fixed airplane attitude reference. However, The large speed differential between the highly dynamic take-off speeds and the long exposure cruise speeds of the HSCT may preclude the HSCT designer from utilizing such relationships.
- (c) A display using a multiple-range, fixed airspeed scale with moving pointers should be designed so that take-off, cruise, and approach speed indications are displayed within 15 degrees of the horizontal line from the fixed airplane attitude reference. If range switching is required on the display, the switching point should be unobstrusive and not detrimental to the pilot's airspeed control tasks or his interpretation during dynamic speed changes.

(3) The airspeed and/or altitude display that is closest to the primary attitude display are considered the primary displays.

(4) If instrument Landing System (ILS) raw data is displayed on both the Horizontal Situation Display (HSD) and the Vertical Situation Display (VSD), the scale should appear on the same side. If the scale is one that is multifunctional, then it should be labeled when it is not in its basic function.

(5) Standby instrument locations should be such that both the Captain and First Officer have access to them.

B. Reversionary Display Modes

Primary display screen failure may dictate the use of an alternate display screen and the presentation of a "compacted format" within a reduced screen size. The compacted display, out of necessity, should retain the critical elements of the primary format with airspeed, attitude, and altitude displays remaining in their respective relationships. All of the normal functions do not have to be present on the compacted display, but those that are present should have identical operation as the primary display. In the HSCT, where the primary flight display is the "window to the world", the reversionary display should be used by the pilot not flying the aircraft. The pilot having the use of the primary display screen should function as the pilot flying, and crew duties should be adjusted as required to accommodate the situation.

C. Primary Flight Displays

(1) The use of a centrally mounted, large screen (18" X 32"), wide-angle vertical situation display (VSD) is recommended for the HSCT. This display should provide the forward-looking image of the landing area, including runways, taxiways, and the immediate surroundings, in a three-dimensional (3D) perspective with ILS/MLS guidance symbology overlaid. This type of display will integrate all of the air data, attitude, navigation, alerting, and annunciation functions, while removing their discrete instrument counterparts. The raw data aircraft control parameters necessary for manual control (attitude, airspeed, altitude, and heading) should still be positioned on the display in the conventional "T" format as described in paragraph IV.A.

(2) Airspeed displays must provide the same "quick-glance" interpretation as attitude indicators to the pilot. The "quick-glance" convenience of round-dial displays may be difficult to duplicate on moving scales that will be integrated in the central large-screen display in the HSCT. Scale length provides a means of supporting the "quick-glance" capability. The minimum visible airspeed scale length that has been found acceptable for moving scales on jet transports has been 80 knots. This minimum has been based on typical scale attributes and subsonic operational speed ranges. The HSCT, destined to operate beyond the current transport speed ranges, must be looked at independently and scale ranges appropriate for its operational capability must be investigated.

(3) Altitude displays present special design problems in that: 1) the ratio of total usable range to required resolution may be a factor of ten (10) greater than for airspeed or attitude, and 2) the consequences of the pilot losing sense of context of altitude can be more catastrophic than that of airspeed and attitude - particularly during critical phases of flight (i.e., takeoff and landing). The combination of altimeter scale length and markings should be adequate enough to allow sufficient resolution and look-ahead to accomplish precise manual control in level flight and estimate ver-

tical altitude change to effect and control level-off. Suggestions for various display enhancements are provided below:

- (a) Provide radio/radar altimeter information on a scale that could be visually related to ground position. The use of such a display could be useful in providing an awareness of terrain when flying at low altitudes.
- (b) Provide airspeed scale markings that are relatively fixed. These offer the pilot a "quick glance" to determine the aircraft's speed.
- (c) Provide airspeed scale markings that are configuration dependent. These also offer the pilot a "quick glance" to determine the aircraft's speed.
- (d) The above markings should be predominant enough to provide the pilot a "quick glance" but not so predominant as to be distracting or confusing when operating normally near the speeds.
- (e) Current airspeed values that are presented in digital form should obscure scale markings or other graduations as they pass the current value index.
- (f) Scale markings such as V1, VR, and V2, which are in close proximity to each other, should be presented so that the intended reference values remain distinct and unambiguous.
- (g) Scale unit markings for air data displays that are incorporated in primary flight displays (PFD) are not required (i.e., "knots", "airspeed", "feet", "altitude") if the content of the readout is remains unambiguous.
- (h) Command display guidance may be made available in lieu of actual indications of flight parameters. Command display guidance will be capable of providing the pilot an immediate and unambiguous indication of deviations or corrections.
- (i) Acceptable airspeed scale graduations are:
 - 5 knot increments with labels at 20 knot intervals
 - 5 knot increments with labels at 10 knot intervals if trend or acceleration cues are used or if a digital current value is incorporated
- (j) Minimum altimeter graduations are:
 - 100 foot increments when used with a current value readout

- 50 foot increments with a current value index only

NOTE: Operational requirements may prohibit Category II low visibility operation without either 20 foot scale graduations, or a readout of current altitude

(k) Acceptable design for vertically oriented moving scales are:

- Higher numbers at top or bottom if no trend or acceleration cues are associated with the speed scale
- If acceleration cues are used, an upward motion of the cue should indicate either increasing energy or speed

(l) Automatic detection and switching of failures in the primary flight display should be used to minimize the sudden loss of multiple parameters which could greatly impact the ability of the pilot to cope with immediate aircraft control tasks during critical phases of flight

(4) Attitude displays should provide an easy, quick-glance interpretation for all expected unusual attitude situations and command guidance display configurations. During normal maneuvering flight, the pitch attitude scaling should provide a visible horizon in the display with not less than 2 degrees of pitch margin available. At extreme attitudes (XX°pitch and XX°roll) there should more than 2 degrees of pitch margin available. Extreme attitude symbology should automatically appear at either of the above degree limits. In addition, automatic "decluttering" of the primary flight display (PFD) should occur at these extreme attitudes. The PFD should retain information that is essential to maneuver the aircraft to a safe attitude and maintain positive control of the aircraft during the maneuver. Primary and secondary attitude displays must be capable of providing accurate attitude information to the pilot throughout 360° of roll and +/- 90° of pitch.

Both fixed airplane attitude reference and reference bank angle pointers ("sky pointers") are approved for quick-glance attitude references. Attitude displays should not include a mix of both types.

(5) Digital, analog, and/or combinations of both should be used and evaluated on the basis of pilot interpretation and the effects on pilot workload.

(6) Display controls should be selected based on the requirements for either two-dimensional or three-dimensional control surfaces. The use of two-dimensional or "touch" type control surfaces give the display designer the opportunity to embed within the display a touch-sensitive control that eliminates the need for mechanical control knobs. Since the two-dimensional, touch-sensitive controls do not have the tactile characteristics of the 3-D knobs or switches, differentiation of controls should be enhanced through the use of distinctive colors, shapes, or designated locations. Selection or deselection indication of two-dimensional controls may be augmented by an appropriate aural signal. Whenever there is need to locate display controls outside of the immediate vision area of the pilot, the use of three-dimensional controls must be considered. The advantages of three-dimensional controls are numerous and the

specific design of these type of controls must be based on the application of accepted human engineering principles.

D. Part-Time Display of Information

Joint airworthiness regulations (JAR) require specific information to be displayed to the pilot, however, in many cases, the information display need not be continuous. Due to display component limitations, it may be desirable to inhibit the display of some parameters except for times where the parameter is required to operate the aircraft. The criteria to be considered when the designer is proposing a part-time display of information is listed herein.

- (1) Use a part-time display if the continuous display is not required for safety of flight reasons.
- (2) Use the part-time display if the parameter can be automatically displayed during the phases of flight where it is used and/or required.
- (3) Use the part-time display if the inhibited parameter is able to be automatically displayed when its value indicates an abnormal condition or when the parameter reaches an abnormal or out-of-tolerance value. This is a consideration only if the inhibited parameter is essential to take the required action or it is needed to enhance the awareness of a specific situation.
- (4) Use the part-time display if the pilot has the capability to manually select an inhibited parameter without interfering with the display or other associated displays.
- (5) Use the part-time display if its failure effects can be designed to meet the requirements of JAR 25.1309.
- (6) Use the part-time display if the automatic or requested display of the inhibited parameter does not create unacceptable "clutter" on the display. During dynamically changing flight conditions, many inhibited displays may simultaneously be introduced to the pilot thereby causing multiple "pop-ups" and confusion. This must be considered by the designer and the proper prioritization of parameter inhibit/display should be a major consideration.
- (7) Suitable alerting should be provided to the pilot if the presence of a new parameter is not sufficiently evident. Alerts may be in the form of visual enhancements (flashing parameter) or aural enhancements as applicable to the flight phase or existing conditions.

VII. SWITCHING AND ANNUNCIATION

A. Electrical Power Transients/Interruptions

- (1) Valid aircraft attitude information (pitch and roll angle) must be available to the pilot no more than one second after electrical power transients to the electronic attitude display (EAD). Electrical power distribution must be designed so as to minimize power transients to both displays at the same time. Any electrical power interruptions

or transients that last beyond one second must not interfere with the ability of the pilot to obtain "quick glance" attitude information during a critical phase of flight.

(2) Electrical power transients that are caused by normal electrical load switching (i.e., boost/hydraulic pump actuation, generator paralleling, lighting, galley operation, etc.) should have any significant effects on the displays. Abnormal electrical transients such as generator failure should not cause an initialization state or "cold start" condition in any of the displays.

(3) Any large electrical loads such as restarting an engine should not affect any display that is required to operate in an emergency condition.

B. Electronic Display Failure States

(1) A "cruise" mode for any display may be considered if this mode provides the pilot the minimum information for safe operation of the aircraft during this phase of flight.

(2) The Captain and First Officer displays should be driven from independent computer sources. If failures cause both pilots' displays to be driven from a single computer source, a clear, cautionary alerting should be available to both pilots to ensure that each has sufficient awareness of the existing display operating state and failure limitations.

C. Source Switching and Annunciation

The *type* or *source* of information that is displayed on the PFD may have its meaning changed through automatic or manual mode or source selection. When this occurs, then the mode or source must be totally unambiguous from the format of the display or from the appropriate annunciation.

(1) Independent sources are required for Captain and First Officer attitude, heading, and air data on their primary displays. During normal, independent source operation, there is no need to provide annunciation of these sources. However, when there is need to revert to alternate sources, then each pilot position should have the appropriate annunciation to alert them to the existing condition. In addition, some attention-getting feature should be included in the annunciation to ensure that the affected pilot position is adequately alerted to the present condition.

(2) A variety of headings may be available to the pilot. When magnetic heading is being displayed, there is no requirement to annunciate this configuration since it is normal operation. If the pilot chooses to select either a true, grid, or ground course (aircraft track) heading, then the appropriate annunciation must be made at the appropriate pilot station. If the heading mode that is selected is not compatible with the orientation of an external navigation aid (i.e., Magnetic North oriented VOR vs. true heading on the display), then a clearly defined display attribute must be developed to ensure that there are no geometric disparities between the two different displays.

(3) Annunciations within electronic displays must be consistent in their labeling as the mode/source selection controls. This is called "control/display compatibility".

VIII. MAP MODE CONSIDERATIONS

A. Readability and Discrimination

All primary mapping or navigation displays that have overlaid radar returns included in the display should ensure that the map and navigation display symbology remains easily readable and easily discriminated from the radar data.

B. Route or Course Line Presentation

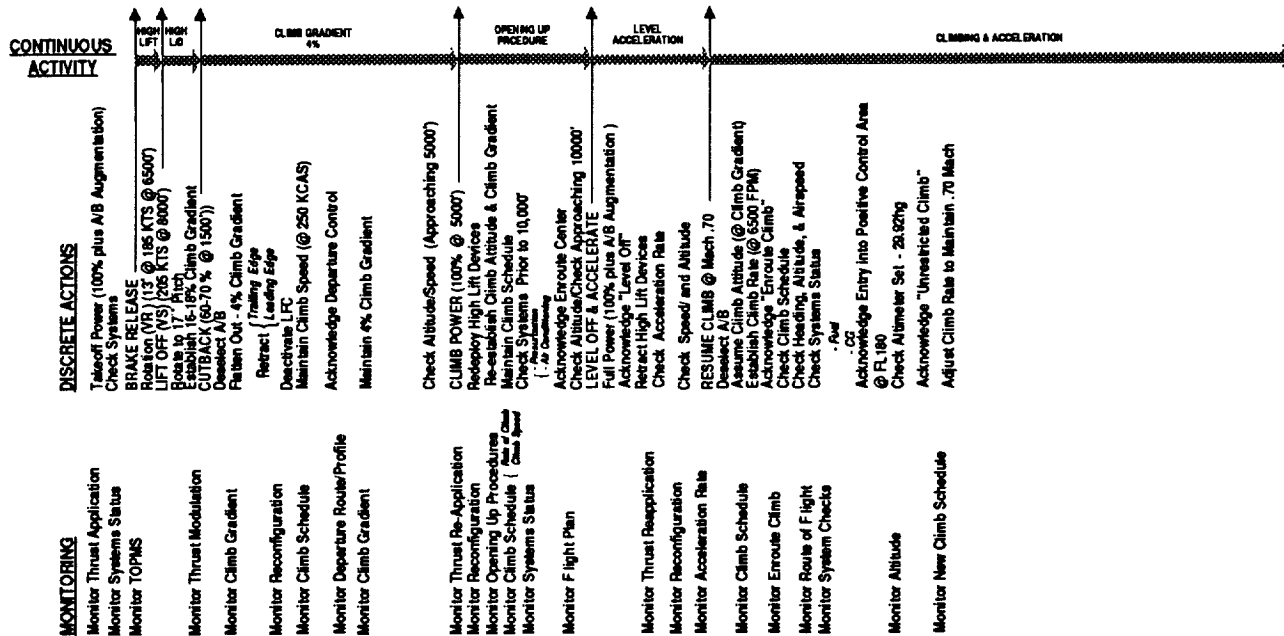
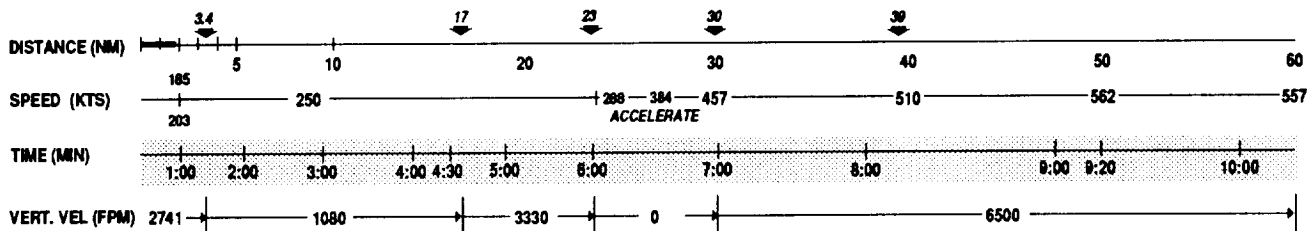
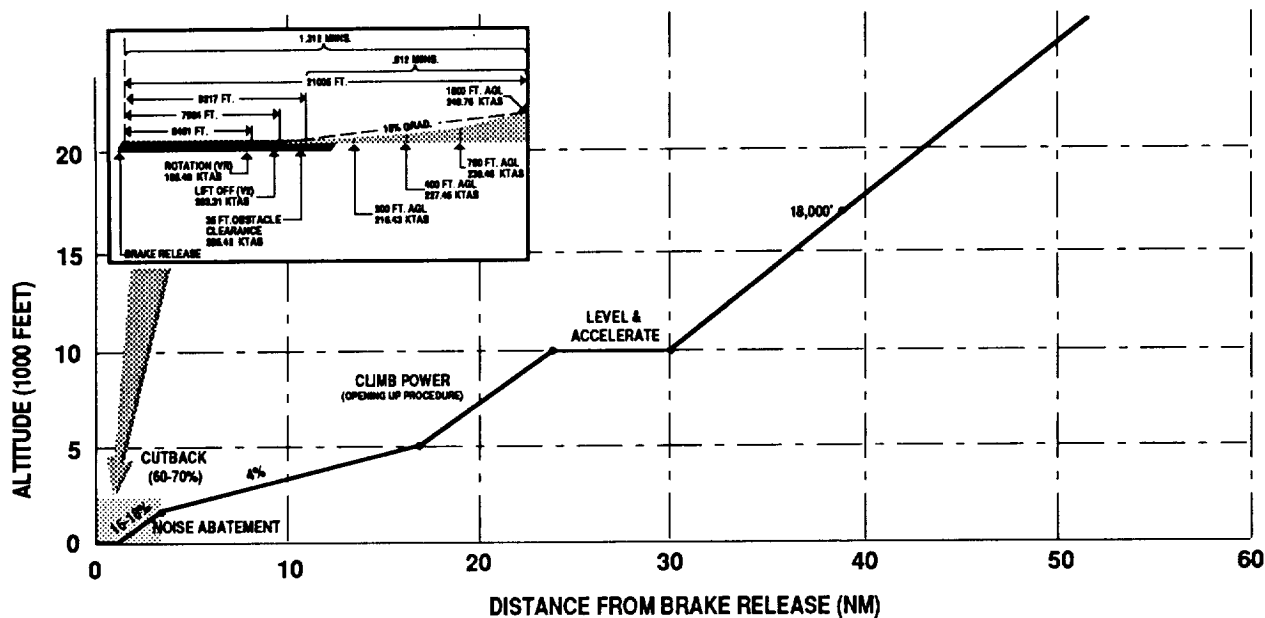
Whenever there are route and/or course lines presented on the map display, the display should provide adequate interpretation to allow the pilot to maintain aircraft course, either manually or on autopilot, within the course errors limitations as defined in DO 187.

C. Map Displays

During VOR instrument approaches it is permissible that map displays may be used by both pilots providing the map display meets the requirements in paragraph VIII. B, above. If both displays are in the map mode, the navigation sensors and their associated computers must be compatible with the performance requirements and obstacle clearance zones associated with the type of approach that is being performed.

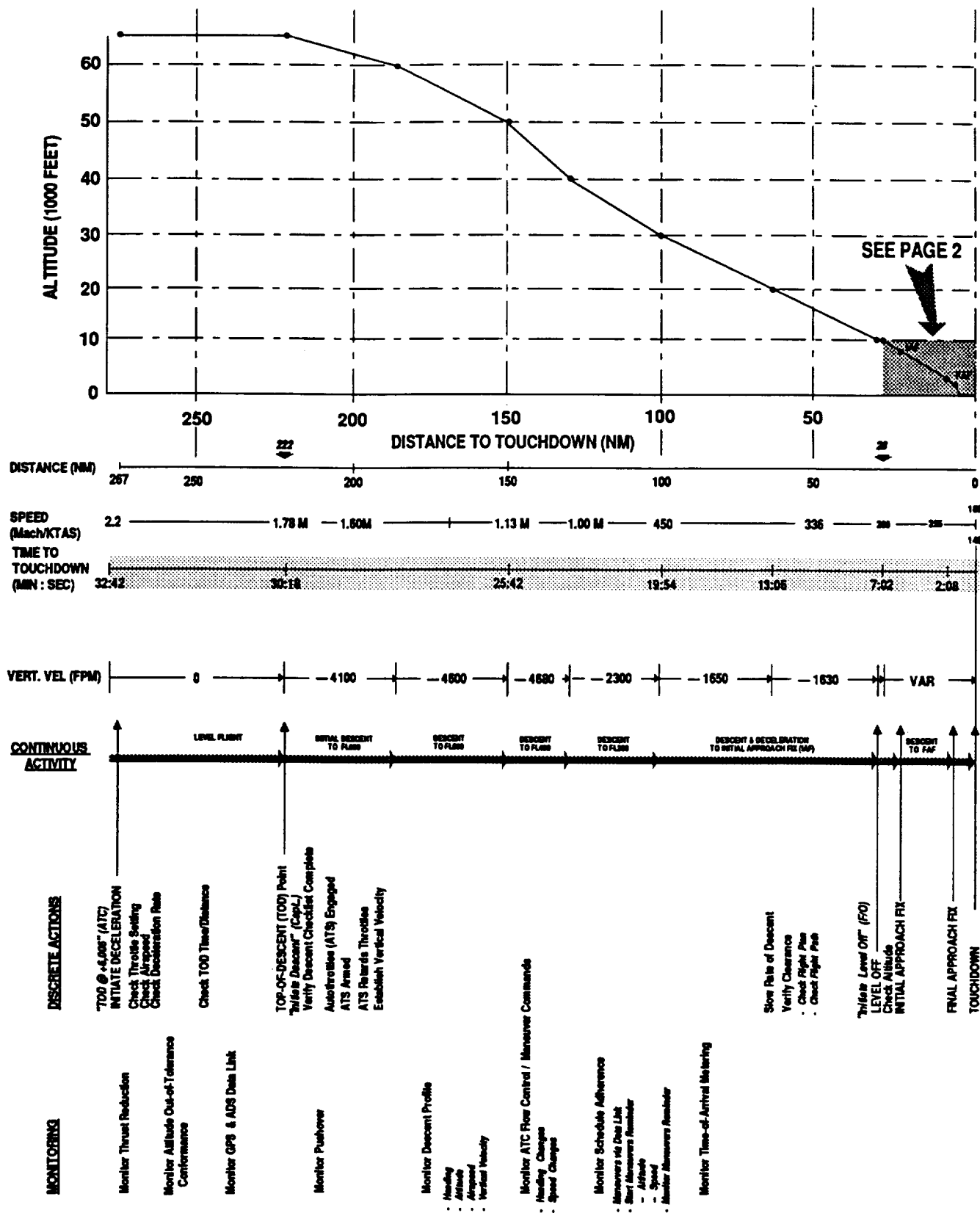
IX. SYSTEMS STATUS DISPLAYS

System status displays must be compatible with system failure conditions and phase of flight. System component status symbology should be logical, easily interpreted, and consistent with other control/displays. System status display color selection should be compatible with paragraph IV.A of this document.



HSCT TAKEOFF/DEPARTURE PROFILE

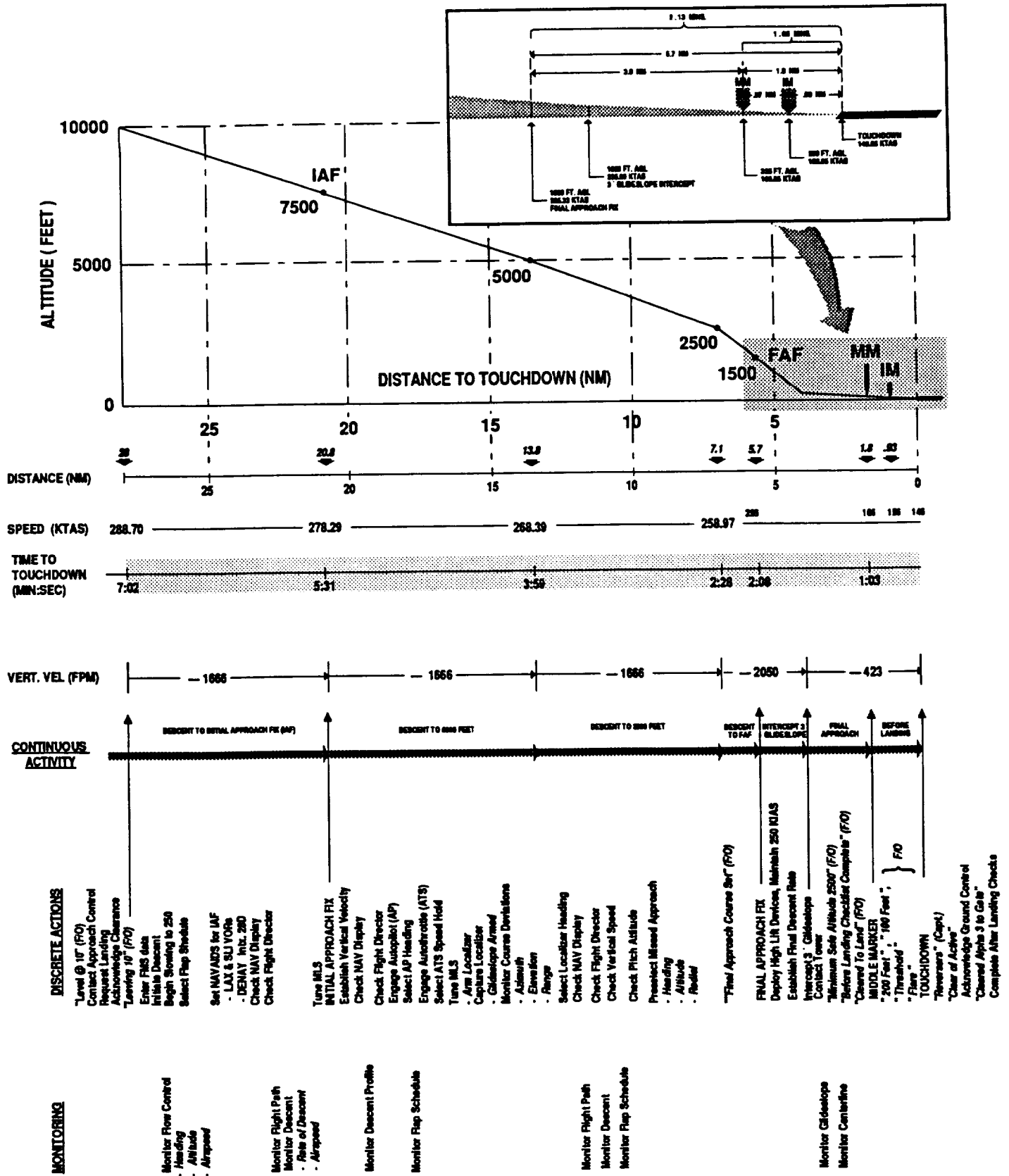
FOLDOUT FRAME



HSCT

FOLDOUT FRAME

2



APPROACH / LANDING PROFILE

APPENDIX I

"Fasten Your Seat Belts"

The sleek, dart-like projectile remains poised at the end of the runway. As the Captain receives the command "Cleared for takeoff" and selects full power, the vehicle lurches forward and begins a slow and then rapid acceleration towards lift-off speed. On the flight deck the First Officer calls "V1" and the sharply pointed nose abruptly rotates skyward. As the massive undercarriage leaves the ground, the Captain, calls in rapid succession, "gear, flaps, max rate climb". The long, slender aircraft is airborne and pointed towards the stratosphere and eventually it's supersonic cruise speed. However, before it can achieve this, it must overcome a number of competing performance and environmental factors. Takeoff performance and airport noise abatement procedures must be balanced in such a manner as not to compromise safety.

You have just been introduced to the world of the High-Speed Civil Transport; or HSCVT, an intercontinental, commercial jet aircraft capable of carrying 300 passengers over 5,000 miles non-stop. In transit, and on the edge of space, this ultra-high performance vehicle exceeds the once dreaded 'speed of sound' with impunity. Enroute, however the flight must deal with a number of assaults on nature, including atmospheric emissions (as well as noise). To cope with these violations on the environment, by technology, a series of regulatory and procedural restrictions, designed to minimize the impact and/or negate the damage, will have to be met. These include convoluted departure patterns; intricate altitude and speed profiles; and multiple changes or reconfiguration of the flight, propulsion and control systems, and even the airframe itself; to say nothing of the additional workload imposed on the crew to monitor and supervise those complex and sophisticated air vehicle alterations. Of course, unprecedented system automation is available to assist them, but the ultimate responsibility for safe and efficient flight remains the crews'.

Once full power is applied, the crew's attention is focused on the flight deck console where a heads-up, three-dimensional graphic depiction of the runway ahead is stereoscopically displayed. When the engines reach maximum thrust, the brakes are automatically released the runway image begins moving providing the illusion of rapid acceleration on the screen in front of the crew. Below the large screen 3-D view of the runway, mounted horizontally, is a top-down map display showing the planned departure route. As the automated flight control system rotates the aircraft to the precise lift-off attitude, the crew follows through on the side-stick hand controllers. As liftoff occurs, a highly-integrated flight-propulsion control system automatically begins to program a reduction in thrust in order to further minimize the sideline noise at the airport.

As the aircraft crosses the airport boundary it begins to automatically reconfigure aerodynamically in such a way that noise abatement power can be reduced to a safe minimal level. The high lift devices are changed to achieve optimum lift/drag ratios. In addition to monitoring these changes and verifying that the appropriate alterations in performance occurs, the crew's major focus is on compliance with the departure clearance and assuring that the noise contours do not encroach upon populated areas. Safely airborne the large screen, is transformed to a "highway-in-the-sky" image of the computed flight path as projected in space. This three-dimensional ribbon twists and turns as the pre-programmed departure route, the flight management system will follow, is projected ahead. At the center of that flight path presentation is a symbol of the HSCVT superimposed on the pathway with colored chevrons indicating compliance with specified rates of climb and turn. The crew's major responsibility

is to monitor these graphic displays and cross-check aircraft present position which appears as a "ghost" like image against a pictorial God's-eye view of the departure path on the map display. There is little else they can do, for the vehicle has no windows, and is being controlled by machines! Controlled by a highly complex and sophisticated system of integrated flight and propulsion mechanisms that are computer driven in accordance with the pre-programmed flight path requested prior to takeoff, which optimized route, altitude and speed for maximum efficiency. Yet, the duties and responsibilities of the crew are no less awesome or mentally taxing.

The particular departure route has been pre-specified to provide a flight path corridor which can accommodate steep climbs and avoid population centers; yet be compatible with optimal fuel efficiency. The route and clearance were established prior to takeoff and calculated to a precise gate arrival time at the destination. En route if any changes are required, they are automatically data linked to the onboard flight management system. Unlike conventional ATC instructions which specify flight parameters (e.g., headings, altitudes, and airspeeds), these command vehicle trajectories (e.g., turn rates, vertical velocities, and acceleration changes) to achieve near continuous changes in the flight path vector and ensure precision air traffic flow throughout the flight. Position reporting and inflight weather data are automatically downlinked in order that flight progress and potential conflicts can be continuously monitored and resolved on the ground. Again, the crew's primary concern is to monitor any anomalies in the pre-planned route and profile as depicted on their moving map displays. They are not concerned with specific headings, altitudes, and speeds, which may continuously change so as to maintain proper traffic flow, but rather attend to any deviations from commanded values as dictated by the ground control. Such an operational environment is markedly different from that of today's conventional subsonic transports, where the crew's role is predominantly tactical rather than strategic as in the above scenario.

Once clear of any noise sensitive restricted areas or over the coastline with nothing but open ocean lying ahead, the message "Cleared for unrestricted climb on Sierra November to FL600, maintain Mach 2.4 until TOD" is received on the Data Link screen. The Captain acknowledges by pressing a "Roger" key and then watches as the throttles automatically advances.

The propulsion system is automatically changed to a unsuppressed mode providing more efficient climb performance and in a configuration for transonic acceleration through the sound barrier at approximately FL300. From this point on, the crew's primary responsibility is supervision. That is ensuring that system performance and the route of flight remains within the prescribed limits and clearances. Not until they initiate deceleration and descent in anticipation of landfall, will the level of activity intensify again. Only after completing setup for an automatic blind approach and landing, with arrival at the gate within seconds of its planned time, half a world away in half the time, can the crew relax. And as the "FASTEN SEAT BELTS" sign is extinguished they can rest assured that another successful High Speed Civil Transport flight has been completed!

APPENDIX J

"Prepare for Landing"

Some six hours and 5,500 miles after lift-off, the Captain commands "Initiate Deceleration", as the HISC approaches the precalculated Top-of-Descent (TOD) in response to an ATC data-linked TOD Reminder Message. As the HISC slows from its cruising speed that is greater than twice the speed of sound, in preparation to begin descending from an altitude in excess of 12 miles, the crew once again becomes a flurry of activity while reconfiguring the vehicle for reentry into the less rarefied atmosphere.

At the precise time and position established by a Global Positioning System (GPS) and verified throughout the oceanic track by Automatic Dependent Surveillance (ADS) at TOD, the HISC pushes over for descent. During the next 24 minutes, over some 200 nautical miles, the HISC will slip back through the sound barrier; configure itself for subsonic flight; and reenter the low altitude Air Route Traffic Control (ARTC) structure; all while the crew simply monitors this automated sequence of events. Upon leveling off at 10,000 feet, the crew requests, from Approach Control, landing clearance at their destination to coincide with a preassigned gate arrival time.

The pilot acknowledges the displayed clearance message, "Cleared via Initial Approach Fix, MLS/DME Approach, for a straight-in to runway 21R, maintain 10,000 feet, slow to 250 knots, report leaving 10,000 and arriving Final Approach Fix". He then commands entry of the critical flight parameters into the Flight Management System (FMS) before initiating the deceleration to 250 knots. Upon reaching 250 knots indicated airspeed (250 KIAS), the high lift devices are automatically deployed and the First Officer, monitoring this reconfiguration, reports to the Captain, "Final approach course set, begin descent to 1500 feet at 24 miles", via the intercom. He then checks the data link display for the latest weather and local altimeter setting, reviews the displayed Descent Checklist and reminds the Captain again of the final approach course, the FAF altitude, and minimum safe altitude for the surrounding area. Upon reaching and reporting the FAF, the Captain calls for initial rate of descent to be established and the Before Landing Checklist to be verified.

The Captain monitors the automatic approach on the large screen Vertical Situation Display (VSD) which provides a computer-generated image of the final approach path to the airport superimposed on a blending of radar, infrared, and video imagery of the runway, taxiways, and terminal area structures in addition to glide path and course/line alignment indicators. He also cross-checks the progress of the approach on the Horizontal Situation Display (HSD) which presents the final approach path and ground track on a computerized moving map display of the airport area based on a digital terrain database of elevation and cultural features. Headings, approach speeds, and rates of descent, are automatically calculated and displayed in terms of deviations from nominal values based upon current air vehicle weight, local weather conditions, and the ATC-provided clearance. The Captain simply verifies that all flight parameters remain within the prescribed tolerances and that they are in compliance with the precalculated and/or cleared limits. If they are not, then manual intervention may be required, based on computer-aided diagnosis and prescriptive recommendations for corrective action.

The final approach clearance, "Cleared to runway 21R", is acknowledged and an approach speed of 145 knots is set. The First Officer calls "Outer Marker" at seven miles and "Inner Marker" at one mile, as well as altitude every 100 feet during the descent on final. As the

HSCF crosses over the Localizer, 1,000 feet from the end of the runway and 100 feet altitude, the autothrottle system begins to reduce power and at 7 feet above the runway, the autopilot initiates a slight rotation while crossing the threshold. Upon touchdown, the Captain calls for full thrust reversal as the gangling bird alights firmly on the runway and lurches forward upon deceleration. The ground controller calls, "Cleared for high speed exit when slowed. Taxi Alpha 3 to gate".

The First Officer monitors the "After Landing Checklist" completion, as the Captain selects the airport terminal map on the HSD and reviews the Alpha 3 route to their gate. The large screen VSD has shifted perspective to a ground-referenced view of the taxiway, a series of stop bars similar to traffic lights, and a sensor imagery of any ground obstructions (such as ground vehicles or other aircraft) in the immediate vicinity. Upon reaching the gate and applying the parking brakes, the engines are shut down; after receiving a call from the ground crew indicating that the chocks have been inserted and the safety pins installed.

The Captain and First Officer glance around their respective crew stations to ensure that everything is secured, the computer data dump from the On-board Maintenance system (OMS) is in progress, and the Electronic Library System (ELS) is configured for ground operation. After all of the passengers have disembarked, the Captain and First Officer deplane and remark as they leave the airplane, "A zero-zero night landing. I'm sure glad we're flying this bird and not one of those...", pointing to a brand-new 21st Century mega-transport that is parked alongside.

APPENDIX K

"The Path To The Future" The Evolution of Flight Deck Automation

The first generation of air transports incorporating any automation (e.g., Boeing 707, Douglas DC-8) were limited to simple electromechanical guidance and control systems (i.e., autopilot) for monitoring and controlling the flight path during cruise and simple warning systems for alerting the crew to system malfunctions. In the second generation, including the wide-body Boeing 747 and Douglas DC-10, automation increased quantitatively rather than qualitatively in terms of information, with the proliferation in warning indicators consisting of a bewildering array of whistles, bells, and lights but little attempt to organize or prioritize that information; leading to increased crew workloads. The third generation transports (e.g., Boeing 757/767, Douglas MD-80, and the Airbus A310) were the first to incorporate electronic, reconfigurable displays; referred to as "glass cockpits". In addition, integrated caution and warning systems and sophisticated flight management systems were also advanced through digital electronic technology and enhanced on-board computational capability. Not only could the information be organized and prioritized, it could also be filtered so the crew was no longer overloaded and could, in fact, be assisted in making decisions by the system which could sort, weigh, and present alternative courses of action. Hence, the age of information management through system automation was born, with a whole host of new and/or revised roles for the flight crew; replacing those of aircraft monitoring and control.

A new generation is now dawning which will include the High-Speed Civil Transport (HSCT) as well as the next generation of advanced subsonic transports and with it the steady progression in system automation and increasing system autonomy will continue. This move forward is prompted not only by technology advances of on-board systems but by compatible advances in automation of providing ground-based air traffic control an increasingly sophisticated and complex operational environment. Computers on the ground will be used to provide continuous traffic management, on a global basis from gate to gate, based on precision trajectory estimation and inflight airborne weather data updated by real-time digital data and air-ground linking. In addition, regulatory constraints and environmental restrictions related to noise abatement, emissions control and airport compatibility will impose limitations upon optimal operations; performance as well as economic.

In the case of the HSCT, such operational considerations will be particularly onerous in light of the unique characteristics inherent to supersonic flight such as sonic boom management and ozone depletion. The features required to deal with the HSCT's uniqueness will undoubtedly impose an additional workload on a two-man crew, which is already marginal on advanced technology transports. For example, integrated propulsion and flight systems required to rapidly and safely propel the aircraft up and away from the airport, to minimize community noise contours, will require an unprecedented degree of automation. Additionally, the removal of man-in-the-loop in order to achieve the necessary precision and timing of specific activities creates difficulties as well in terms of system monitoring. The changes in aerodynamic configuration and thrust management associated with laminar flow control; high-lift devices; variable bypass ratios and inlet/nozzle geometry; and/or throttle/thrust modulation throughout takeoff and climb-out, requires precise orchestration probably beyond human capacity, given the timing criticality. The additional monitoring; of the climb departure profiles to ensure that the sonic boom footprint avoids population centers; of cruise level atmospheric emissions to control ozone depletion; and of high altitude temperature,

pressurization, and/or radiation effects that could be detrimental to either air vehicle or its occupants, all represent increased crew workloads, even with automated assistance.

Hence, HSCT flight deck automation and crew compatibility with the advanced technologies represents a totally new approach to the problems of man-machine design. Add to this the additional difficulty of operating without the benefit of being able to see outside and the non-conventional nature of the HSCT, it's unique flight deck/crew system requirements becomes abundantly clear. Not only will the vehicle and it's operating environment pose new challenges in terms of traditional man-machine integration problems but much of the conceptualization of the crew's duties, the degree of human involvement/intervention required and the appropriate level of system autonomy desired must be based upon an entirely new automation philosophy; albeit "human-centered" in nature. New levels of system automation must be developed and tested, new levels of systems redundancy/reliability must be provided, and new certification criteria must be adopted and validated for an economically viable and environmentally friendly HSCT.

In order to achieve these results in a timely and orderly fashion one final, but critical issue, must be addressed; namely customer acceptance. There is a plethora of unconventional requirements associated with the HSCT and it's operations, including synthetic external visibility; possibility of tandem seating for the two-man crew; as well as unprecedented system automation and autonomy; each placing inordinate demands on the crew. It thus becomes obvious that the HSCT flight deck design and development will require herculean efforts to venture into these uncharted waters. This effort must be initiated early in the conceptual definition phase and sustained throughout the entire design and development. Anything less would strain credulity and jeopardize customer acceptance which, in the commercial world of aviation, could well be as important as the economic and environmental considerations.

APPENDIX L

"To See or Not To See"

Over the years it has been recognized that nearly 50% of all commercial airline accidents occur during the approach and landing phases of flight and further that at least 75% of those accidents are due to human error. The predominant cause for such errors is generally attributed to difficulties associated with visually guided flight in less than perfect visibility (e.g., night or in the weather).

The primary means of guidance and control of an aircraft is through the eyes of the pilot who uses both static as well as dynamic visual cueing during approach and landing. Static cues such as shape, size, and location of the runway are used to maintain attitude and glideslope. Dynamic cues such as scene expansion and visual flow enable the pilot to make horizontal and vertical position alignments relative to a fixed aimpoint on the runway.

The performance-limiting and/or error-producing of human visual capabilities are well established including a host of biases and illusions leading to misinterpretations or faulty judgments. The conclusion is that the visual sense, although adequate under ideal conditions, degrades rapidly in reduced visibility due to misperceptions in either static and dynamic cueing.

In his recent treatise on "Human-Centered Aircraft Automation", Dr. Charles Billings, Chief Scientist, NASA Ames, has indicated that there are, "very few flight maneuvers that require such precision that they have been entrusted only to automation. Category II and III ILS approaches, are an example".¹ He goes on to state that, "it has been generally accepted that pilot perceptual capabilities may not be sufficient to permit a safe landing from approaches under these very bad weather conditions."

The limits for manual landing have been established at 1200 feet runway visual range (RVR) and a 100 foot decision height (DH); anything less is a Category III landing, in which the primary mode of operation is automatic. Yet, no one pretends that the flight information available to the pilot under such conditions is adequate for a manual landing.

It has long been contended "that the automation of flight-critical systems is acceptable only when the pilot is provided with sufficient information to evaluate the product of the automated process and has the ability to assume manual control of that process."² Automatic landing systems are cited as a prime example in which the crew must at all times be provided with sufficient information and access to be able to manually control that system. As previously indicated, the primary issue is what constitutes *sufficient information* and what is the source?

The flight information required for manual landing must enable the pilot to assess not only position but the vector of the aircraft in relation to the desired path throughout the approach as well as during flare and touchdown. With conventional cockpits and instrument panels, vector information is not supplied directly, the displayed position information is presented in

¹ Billings, Charles E., *Human-Centered Aircraft Automation: A Concept and Guidelines*, NASA Tech. Memo 103885, August 1991.

² Oliver, J.G., Hoagland, M.R. and Terhune, G.D., *Automation of the Flight Path - The Pilot's Role*, Proceedings of SAE Symposium on Behavioral Objectives in Aviation Automated Systems, October, 1982.

a way that it becomes increasingly inadequate and the information relative to landing flare is missing altogether. Additionally, it is often asserted that there is no difference between the information required to manually perform this task and that required to determine if an automatic system is satisfactorily performing the task.

It is possible, however, to provide displays that would provide the pilot with the quality of instrument information and flight path guidance necessary to perform manual landings without outside references. The Air Line Pilot's Association (ALPA) has stated the basic requirements for an acceptable instrument display for monitoring Cat III automatic approach, landing, and rollout.³ Fundamentally they consist of what the pilot must continually know:

- a) What is the aircraft position (i.e., relative lateral and vertical displacement from desired flight path)?
- b) Where is the aircraft going (i.e., its flight path vector)?
- c) What is its energy status and trend?

Regarding where the aircraft is; ground-based navigation aids, such as ILS, provide a localizer signal which can be used to show the aircraft's horizontal angular displacement relative to the extended runway centerline and an angular displacement above or below the desired path in the vertical plane on a glideslope. These two information sources will inform the pilot immediately and exactly how far and in what direction he is off course.

Regarding where the aircraft is going; the aircraft's direction of flight is not directly displayed with conventional instruments. Heading, which is different from the lateral direction of flight, and in the vertical plane, pitch, must both be adjusted to provide the actual angle of the flight path. Both are affected by weight, airspeed, and winds. To display direction of flight directly, an airplane-like symbol called the "flight path vector" is utilized, which shows direction of flight both laterally and vertically; responds to both pitch and roll rates; and becomes a natural focus of attention during low visibility approaches. It provides the pilot with an indication of where the aircraft is going (not where it is pointed) as well as timely feedback of the effect of control inputs. The flight path vector's behavior provides one of the first indications of disturbance from nominal and stable conditions, such as windshear or automation anomalies. It also provides an effective means to assume manual control by merely placing the vector symbol where it should go and holding it there while things settle down.

Finally, regarding energy status and trend information, the conventional display of airspeed is inadequate, as is angle of attack. What is needed is an energy management symbol which accommodates wind changes and includes certain aspects of groundspeed and acceleration. One suggestion is to provide chevrons that move up and down relative to the wingtips of the vector symbol. This movement would show potential flight path with respect to the horizon which is the flight path angle that can be made good without speed changes at the current throttle setting; or "thrust-minus-drag over weight".

These three fundamental types of information are required to enable pilots to monitor Category III automatic landing and manually assume control should that automation fail. Such information presents a "total flight situation" of where you are, where you are going, and what your energy status is. Its display must be integrated and centered about situational, not command information. And if there is no "see-to-land" requirement, then these displays need not be head-up nor compatible with the external view of the world and/or visual references

³ Oliver, J.G., et al *Automation of the Flight Path - The Display Required*, Ibid.

and cues. Such integrated flight deck displays are achievable with today's technology and are being developed in support of the High Speed Civil Transport and its vision-less cockpit.

The fact that an aircraft has no external visibility hence may not be a fatal flaw. We have known for years that aircraft can be flown "blind" and that guidance and control information can be provided artificially. Flight instruments, for example, are intended to augment, or in some instances replace, natural vision cues. Aircraft attitude and airspeed, in addition to heading and vertical velocity, has been presented on instruments for years. More recently electronic displays indicating aircraft geographic position, three-dimensional flight path perspectives, and pictorial representations of systems status have been developed to assist the pilot. Ground based navigation aids also provide information sources that can be used for guidance and control in approach and landing without the benefit of external visibility. As the on-board computational resources and the precision of the external positioning and navigation devices increases, the risks of restricted visibility landings have decreased. Thus, zero-zero (Category IIC) landings are increasingly becoming a technically viable option.

Sophisticated flight management systems provide both lateral and vertical guidance and control in today's advanced commercial aircraft. Additionally, an automatic flight system integrates an automatic pilot, throttle, and landing systems with a flight director through redundant flight control computers which directs correct pitch, roll, and thrust in response to flight management computer commands. Supplement these on-board systems with new satellite-based communication, navigation, and surveillance technologies such as digital data linking, global positioning networks, and automatic dependent surveillance and the ability to enhance guidance and control, minus visual cueing, on approach and landing is impressive. Add to this multi-sensor imaging, computer generated imagery, and digital terrain data combined with high speed filtering, processing, and fusing, and the potential for vision-less flight is unlimited. The confluence of all of these advanced technologies into a "synthetic vision" system which provides technical feasibility and validity to the notion of a HSCT without a droop-nose as a viable concept.

Hence, the HSCT and its synthetic vision system will enable the two-person crew to make automatic Category III landings safely and reliably, on every approach, regardless of the weather and without the benefit of any external visibility. Should manual backup ever be required, sufficient guidance and control information is available from multiple sources to enable the pilot to enter "the loop" and assume manual control of the flight path to a safe touchdown and rollout. User acceptance, however, could still be a problem even though the reliability and repeatability with such an automatic landing capability should rapidly translate into increased confidence in, and proficiency on such a system. Thus, the technological challenge may be less than the psychological one!

APPENDIX M

Revision To Side-By-Side Configuration

An alternative configuration for the original side-by-side was prepared based on the use of a large screen display with dimensions of 15" X 30" in lieu of the NASA-utilized 15" X 40" horizontally-installed display. The reduction of the the large screen display to 15" X 30" produced the following effects:

- Allows for the side-by-side seating arrangement to be moved forward approximately 32". This reduces the distance between the pilots' ERP to 30" instead of the original 40". This positions the side-by-side arrangement at the identical location of the aft crewmember position that is currently shown on the offset tandem configuration.
- Reduces the diameter of the cockpit at the pilots' position to 87" instead of the original 94".
- Reduces the diameter of the cockpit at the large screen display position to 82" instead of the original 88".

Moving the pilots' positions forward 32" permits the lateral distance from the outer wall to the pilots' foot location to remain the same as it was with the original position.

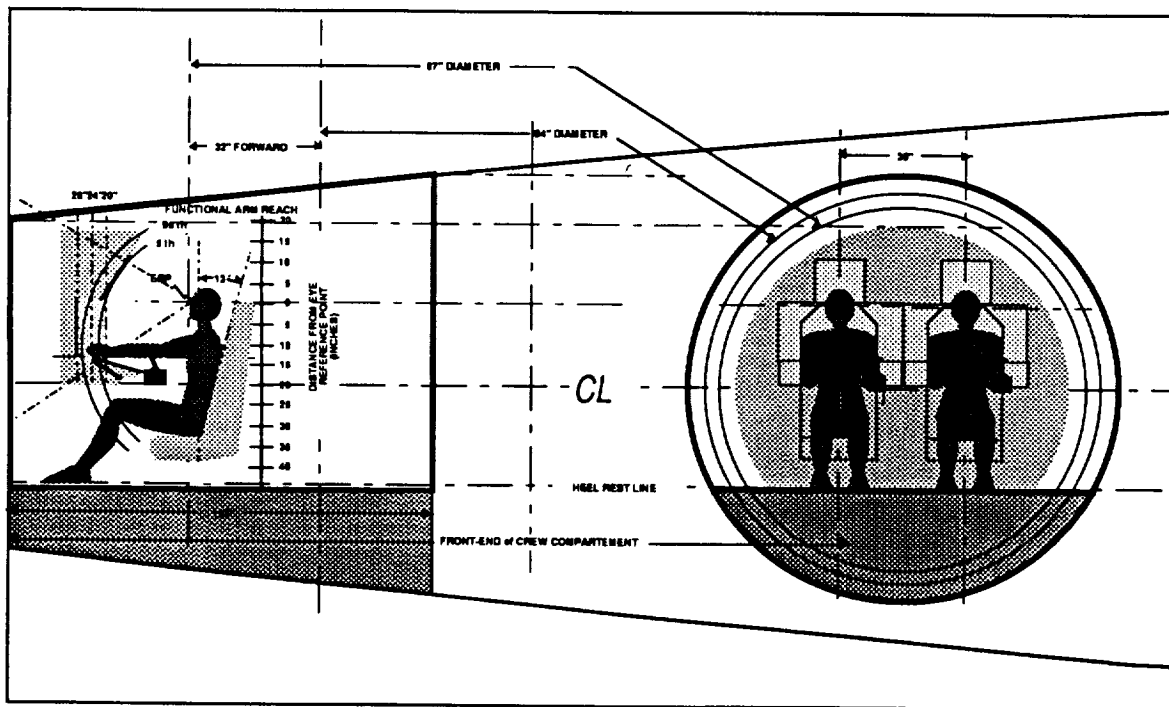


Figure 1. Re-positioned Cockpit Location (15" X 30" Display)

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